ISSN 0147-6874, Moscow University Soil Science Bulletin, 2015, Vol. 70, No. 2, pp. 66–70. © Allerton Press, Inc., 2015.
Original Russian Text © D.G. Krotov, V.P. Samsonova, I.I. Sychyova, S.E. Dyadkina, 2015, published in Vestnik Moskovskogo Universiteta. Pochvovedenie, 2015, No. 2, pp. 30–34.

GENESIS AND GEOGRAPHY OF SOILS

Estimation of Radioactive Contamination at a Model Site in Bryansk Oblast

D. G. Krotov[a]*, V. P. Samsonova[b], I. I. Sychyova[b], and S. E. Dyadkina[b]

[a] *Faculty of Ecology and Soil Sciences, Bryansk State Agrarian University, Kokino village, Bryansk oblast, 243365 Russia*
[b] *Department of Soil Science, Moscow State University, Moscow, 119991 Russia*
**e-mail: krotovd@mail.ru*

Received October 25, 2014

Abstract—The distribution of radionuclides in the soil catena from the bank of the Desna River to the watershed is studied. It is found that changes in the concentration of radionuclides in certain sampling points do not exceed the value of experimental error. The contamination density of ^{137}Cs in the studied area coincides with the values of the forecast maps developed by the Federal Service for Hydrometeorology and Environmental Monitoring. Intense burrowing activity of moles affecting the redistribution of radionuclides is observed.

Key words: radionuclides, flux density, grey forest soils, moles.

DOI: 10.3103/S0147687415020064

INTRODUCTION

The Chernobyl disaster (April 26, 1986) caused radionuclide contamination of vast areas of Ukraine, Belarus, and Russia. The greater part of nuclear power plant (NPP) discharge consisted of radionuclides with short decay time. After the first period, the impact of ^{137}Cs and ^{90}Sr became stronger [1].

The concentration of radionuclides at a certain site of soil cover depends on a number of factors: initial dose, intensity of natural decay, redistribution resulting from wind and water erosion, transport to the deeper soil layers, sorption and desorption, etc. [3, 7, 14]. The zoogenic migration of artificial radionuclides is largely affected by soil animals, mainly because of their high biomass and intense burrowing activity [11, 13]. As a result, the spatial distribution of radionuclides forms a complex mosaic pattern; the minor changes in contamination are reduced and averaged, although they can be noticeable.

MATERIALS AND METHODS

The studies were carried out in the Vygonichskyi region of Bryansk oblast in 2012–2014. This area was exposed to minor contamination as compared with the western parts of the oblast [2].

In order to measure the flux density and the density of soil contamination by ^{137}Cs, ^{232}Th, ^{226}Ra, and ^{40}K, we used a soil catena from the natural levee of the Desna River to the watershed; the length of catena was approximately 5000 m and the elevation difference was almost 50 m. We studied 12 profiles of the catena; the last one (Fig. 1, *12*) was situated in the forest belt and was marked by intense activity of moles. Within this profile, we chose two parallel sample columns at a distance of 20 cm from each other: one of them came

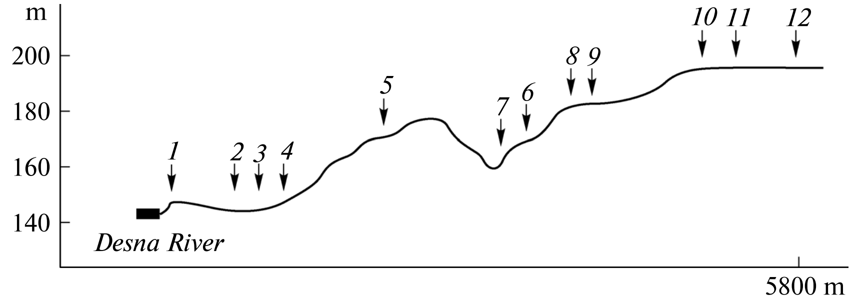

Fig. 1. Location of profiles along the catena (sampling points designated in italics).

Agrochemical properties of the soils of the catena (0–20 cm layer)

Point number (profile)	Location	Soil type	Soil organic matter, %	pH_{H_2O}	P_2O_5, mg/kg	K_2O, mg/kg
1	natural levee	medium-deep alluvial soddy saturated gleyed sandy light loam	1.73	7.15	250	23
2	central floodplain	alluvial drift	4.83	7.15	289	129
3		medium-deep alluvial soddy saturated gleyed sandy medium loam	3.52	6.14	265	52
4	floodplain near terraces	medium-deep alluvial soddy saturated gleyed sandy medium loam	5.22	6.98	395	174
5	I terrace	sod–low-podzolic light loam with loam mantle	1.06	6.94	77	40
6	carbonate outcrop, slope of II terrace, meadow	sod–meadow carbonate	3.65	6.38	27	39
7	gully and meadow	sod–meadow drift soil	4.51	7.00	102	263
8	III terrace and a garden	grey forest light loam with second humus horizon on loesslike loam	2.88	7.19	120	234
9		grey forest light loam on loesslike loam	2.56	6.18	136	141
10	watershed and fallow lands	grey forest light loam on loesslike loam	2.25	5.55	476	138
11		grey forest light loam with second humus horizon on loesslike loam	2.19	5.96	604	178
12	watershed and forest line		–	–	–	–

across a mole passage and the other one came through undisturbed soil.

When studying the profiles, we chose various landscape elements most typical of the area and determined the horizons and soil type (Fig. 1). The studied areas included a broad floodplain with natural levees and lowland areas between ridges; I, II, and III fluvial terraces; an apple garden; fields; and a birch forest belt.

Samples containing a 15 × 15 × 15 cm fragment of a soil horizon were taken mostly from the depth of 0–20 cm (more than 70% of total radionuclide mass is usually located in this layer) [14]. At the watershed, samples were taken from every horizon in order to observe the vertical migration of radionuclides.

The concentrations of ^{137}Cs, ^{232}Th, ^{226}Ra, and ^{40}K were measured by gamma spectrometry with the use of universal radiometric complex Gamma Plus with a SBDG-01 (synchronous brushless diesel generator) detection unit (NaI (TI) detector, 63 × 63 mm) and the spectra processing program Progress 2000. The standard measurement geometry of the gamma line was a 1 dm^3 Marinelli vessel.

For measuring the gamma-radiation dose in the field, we used a DRGB-01 ECO-1M dosimeter–radiometer. The sample collection was carried out at the soil surface and at a height of 1 m; we also collected data on the landscape and vegetation at the sample sites.

The chambers for radon flux density measurement were placed near every soil profile. The radon flux density was measured according to the procedure described in "Method for Measuring Radon Fluxes from Emanating Surfaces" (Niton Research and Development Center, Moscow) in NK-32 accumulative chambers containing SKT-3 activated carbon. The area of radon collection (chamber area) was 32 cm^2; the thickness of the working layer of activated carbon was 0.4 cm; its volume was 12.8 cm^3; the exposure time was 2–4 h. After exposure, the radon activity in the activated carbon was measured by the Kamera-01 package. This was done with the use of gamma and beta radiation of short-lived radon decay products—^{214}Pb and ^{214}Bi—in radioactive equilibrium with radon.

The radon flux density was measured with the use of the applied software. The system measured the activity of radon sorbed in activated carbon within the range from 3 to 1×10^5 mBq/m^2 s.

In addition to the levels of radionuclides, we measured the concentration of organic matter and the level of phosphorus and potassium according to method described in GOST 26213-91, GOST 26207-91, and "Method for Ionometric Detection of Potassium in Hydrochloric Acid Extracts of Soil," respectively [4, 5].

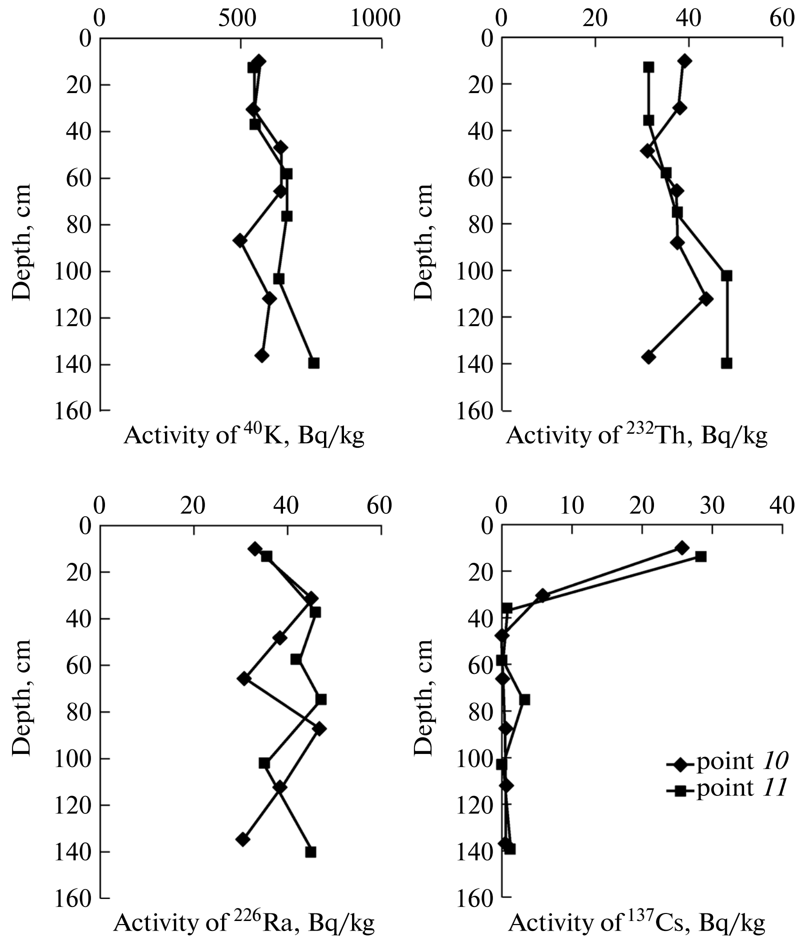

Fig. 2. Profile distribution of radionuclides in grey forest soil (point *10*) and grey forest soil with second humus horizon (point *11*).

RESULTS AND DISCUSSION

Soils of the catena. A number of different soil types associated with certain landscape elements were found in the catena (see Table). Carbonate outcrops lead to neutral and slightly acidic pH of the upper soil layer. The studied soils are light-loamy; the soil of the floodplain is sandy; sod-meadow carbonate soil was found on lime marl, while near the watershed the dominant parent soil is loesslike loam. In the floodplain, the soil organic matter is high, except for the natural levee; in cultivated soils it is medium. Near the watershed, the levels of mobile phosphorus and potassium increase; their concentration is lowest in areas with sod–carbonate and sod–low-podzolic soils.

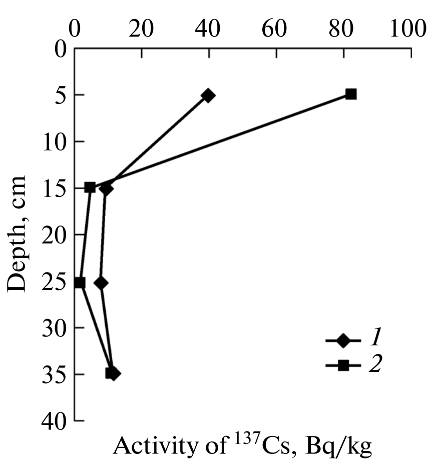

Fig. 3. Profile distribution of ^{137}Cs in grey forest soil (forest line, point *12*): *1*—a mole hill; *2*—undisturbed soil.

Background radiation. The measurements of background gamma radiation showed that the average gamma radiation dose rate at a height of 1 m was 0.12, with a minimum of 0.09 and maximum of 0.13 μSv/h. The average gamma radiation dose rate at the soil surface was 0.13, with a minimum of 0.09 and maximum of 0.15 μSv/h. Thus, no surface radiation anomalies were detected in the studied area.

Distribution of radionuclides in soil profiles. The distribution of a number of radionuclides, such as ^{40}K, ^{232}Th, and ^{226}Ra, was found to be rather homogenous. All the fluctuations lie within the range of measurement errors of the Gamma Plus complex (Fig. 2) [8]; ^{137}Cs is mainly concentrated in the plough horizon (95% and 92% of the total mass in profiles 10 and 11, respectively).

The burrowing activity of animals, in particular moles, is one of the main factors of soil migration of radionuclides. When exposed to all types of ionizing radiation, the soil fauna is depleted. The radiosensitivity of arachnids, woodlouses, and earthworms is significantly higher than that of plants. In contaminated areas, the total density of mesofauna decreases 8–60-fold [9]. Earthworms, which are the main source of food for moles, are exposed to the most suppressive effect. In the areas with increased radiation background, the abundance of earthworms is affected and their development is retarded, as well [11]. As a consequence of the decreased abundance of earthworms, the abundance of moles also decreases. By contrast, moles are more active in noncontaminated areas; this can be evidenced by mole hills—mounds of earth with a diameter of up to 40 cm on the soil surface. Thus, the material of lower noncontaminated layers is transported to the upper parts and the upper contaminated soil moves down. In forests, mole hills can occupy a large area of the soil surface [6]. In our studies, the percentage of the area occupied by mole hills was 6%, which means that mole activity is high.

^{137}Cs is a long-lived radionuclide (half-life 29 years) which is most abundant in the upper 10-cm-thick soil layer in the forest belt; 95.2% of the total mass is concentrated here. However, we should note that the ^{137}Cs concentration in the deeper layers is higher than that in fallow lands; on the other hand, the range of values of the ^{137}Cs concentration in two profiles at a distance of 20 cm is broader than that in fallow lands. The activity of burrowing animals (moles) can lead to abrupt changes in values over small distances and to significant deepening of radionuclides, which is higher than vertical migration associated with water flow.

At a depth of 20–30 cm, horizon B of undisturbed soil (Fig. 3, curve *2*) corresponds with horizon A1 of a mole hill (curve *1*). Because of the activity of moles, the upper soil layer came down and the ^{137}Cs concentration at a depth of 25 cm was found to be almost double that at a neighboring site of undisturbed soil. By contrast, at the soil surface the concentration of ^{137}Cs is two times lower than that near the mole hill, which results from the burrowing activity of moles.

Changes in the concentration of radionuclides along the catena. The levels of ^{40}K and ^{232}Th do not change significantly within the catena (400–500 Bq/kg and 15–25 Bq/kg respectively), except for the minimal values at the sites of chulk outcrops (52 and 4 Bq/kg, respectively). The concentration of ^{232}Th shows a weak tendency to increase from the floodplain to the watershed (from 14 to 35 Bq/kg). The concentration of ^{226}Ra is minimal on the natural levee (15 Bq/kg) and gradually increases closer to the watershed, reaching

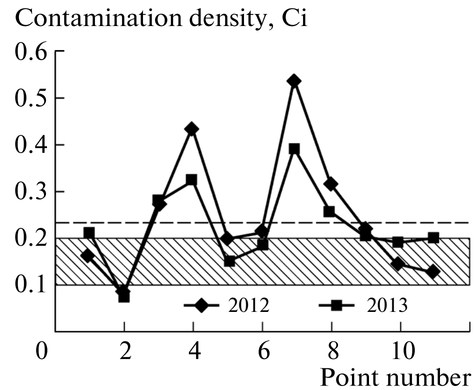

Fig. 4. Changes in ^{137}Cs contamination density along the catena (0–20 cm layer; average experimental value designated by dashed line; shaded area designates 2016 forecast).

the maximum in fallow grey forest soils (37 Bq/kg). In spite of minor discrepancies, the trends in the concentration of radionuclides along the catena in 2012 and 2013 are generally consistent; thus, we consider their spatial distribution as regular and not random.

The values of radon flux density vary widely along the geomorphological profile of the river: from 0 mBq/m^2 at the sites of chulk outcrops (point 6) to 75 mBq/m^2 (2012) and 42 mBq/m^2 (2013) in the central part of the floodplain. The scatter of the radon flux density values may result from the variation of the bedrocks and minerals of the soil. The highest concentrations of radon were observed at the sites of changing of geomorphological features (floodplain border, watershed) and did not exceed the permissible levels (80 Bq mBq/m^2) [12].

Comparison with the contamination maps of Bryansk oblast. According to the Federal Service for Hydrometeorology and Environmental monitoring, in 1986 the studied area was in the 0.2–0.5 Ci/km^2 zone and will be in the 0.1–0.2 Ci/km^2 zone in 2016 [2].

We found that radiocesium contamination of the studied area is consistent with the forecast maps (with lower values at certain points); however, there are points of significant increases (Fig. 4). This confirms that the pattern of contamination distribution is mosaic, in spite of the low and medium levels of radionuclides.

CONCLUSIONS

Thus, no surface radiation anomalies were found in the studied area. The density of soil contamination by ^{137}Cs does not exceed the permissible levels (1 Ci/km) [10]. The main body of ^{137}Cs is concentrated in the working (soddy) layer. In the deeper layers (at a depth of more than 30 cm) the level of ^{137}Cs is extremely low.

The distribution of ^{40}K, ^{226}Ra, and ^{232}Th is homogenous. The distribution of ^{137}Cs along the profile is regressive–accumulative.

The changes in the concentration of radionuclides in certain sampling points over two years do not exceed the value of experimental error.

The concentrations of ^{232}Th and ^{226}Ra show a pronounced tendency to increase from the floodplain to the watershed, broken by local increases in the concentration in lowland relief features and by minimal values at the sites of chulk outcrops.

The concentration of radon is highest at the sites of change of geomorphological features (floodplain border, chulk outcrops, and watershed) and did not exceed the permissible levels (80 Bq mBq/m^2 s) [12].

The contamination density of ^{137}Cs in the studied area coincides with the values of the forecast maps developed by the Federal Service for Hydrometeorology and Environmental Monitoring [15].

ACKNOWLEDGMENTS

This study was supported by the Russian Foundation for Basic Research, project no. 13-04-00480a.

REFERENCES

1. Abagyan, L.A., Il'in, L.A., Izrael', Yu.A., et al., Information about Chernobyl disaster and its consequences prepared for International Atomic Energy Agency, *At. Energ.*, 1986, vol. 61, no. 5, pp. 301–320.
2. *Atlas sovremennykh i prognoznykh aspektov posledstvii avarii na Chernobyl'skoi AES na postradavshikh territoriyakh Rossii i Belarusi (ASPA Rossiya–Belarus')* (Atlas of Modern and Forecasted Consequences of Chernobyl Disaster on Affected Territories of Russia and Belarus (AMFC Russia–Belarus)), Izrael', Yu.A. and Bogdevich, I.M., Eds., Minsk, 2009.
3. Belous, N.M. and Shapovalov, V.F., *Produktivnost' pashni i reabilitatsiya peschanykh pochv* (Productivity of Arable Land and Recovery of Sand Soils), Bryansk, 2006.
4. *GOST* (State Standard) *26213-91: Soils. Methods of determination of organic matter*.
5. *GOST* (State Standard) *26207-91: Soils. Determination of mobile phosphorous and potassium compounds by Kirsanov's method modified in the Central Scientific Research Institute of Agrochemical Service of Agriculture*.
6. Dmitriev, P.P., Khudyakov, O.I., and Lim, V.D., Heterogenety of soils and soil cover in settlements of rodents, *Pochvovedenie*, 1991, no. 8, pp. 127–136.
7. Kokoreva, V.V., Some peculiarities of behavior of radiocaesium in ecosystems of Kaluga oblast, *Extended Abstract of Cand. Sci. (Biol.) Dissertation*, Kaluga, 2007.
8. *Kompleks universal'nyi spektrometricheskii "Gamma Plus": Opisanie tipa sredstva izmereniya* (Gamma Plus Universal Spectrometric Complex: Description of Measurement Type), Moscow, 2006.
9. Nurtdinova, D.V., Influence of technogenic pollution on distribution of the European mole (*Talpa europaea* L.). http://e-lib.gasu/ru/konf/biodiversity/2008/2/29.pdf
10. *Sanitarnye pravila i normativy (SanPiN) 2.6.1.2523-09 "Normy radiatsionnoi bezopasnosti NRB-99/2009"* (Sanitary Rules and Norms 2.6.1.2523-09 "Standards of Radiation Safety SRS-99/2009"), 2009.
11. Simonovich, E.I., Bioindication of radioactive pollutions using soil fauna, *Biol. Nauki,* 2013, no. 7, pp. 48–51.
12. *SP 11-102-97. Inzhenerno-ekologicheskie izuskaniya dlya stroitel'stva* (SP 11-102-97. Engineering-Ecological Exploration for Building), 1997.
13. Turovtsev, V.D. and Krasnov, V.S., *Bioindikatsiya* (Bioindication), Tver, 2005.
14. Kharkevich, L.P., Efficiency of soil treatment methods and agrochemical techniques in production of fodders on radiation-polluted agricultural soils of southwestern Russia, *Extended Abstract of Doctoral (Agric.) Dissertation*, Bryansk, 2011.
15. Migration of radionuclides in environment. http://chornobyl.in.ua/radionuclide-migration.html

Translated by Ya. Atmanskikh