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ENVIRONMENTAL AND FOOD SECURITY

The Effect of Anthills on Grey Forest Soil Agrochemical Properties and Radionuclide Migration in Fallow Lands of Bryansk Opolie

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Abstract—*Formica pratensis* anthills, which occur in great numbers in the Bryansk Opolie fallow land areas covered with the grey-luvic phaeozems, change both the local microrelief and the soil properties. The soil $pH_{KC}L$ in their dome is higher than that in the surrounding soils by an average of 0.6 units. In the top 5-cm soil layer, increased contents of the organic matter and the mobile phosphorus and potassium are recorded, while the cation exchange capacity and the hydrolytic acidity are decreased. The natural radionuclide distribution under and outside the anthill is uniform. The technogenic ^{137}Cs in its maximum is found at a greater depth under the anthill. It may be explained by the ant pedoturbation activities.

Keywords: anthills, grey forest soil, fallow land, agrochemical properties, natural radionuclides, ^{137}Cs

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INTRODUCTION

Spatial variations in the soil properties can be caused by many global- and local-scale factors. The local impact results in so-called "limit structural elements" of the soil cover, which are typically characterized by a small size [21]. However, if many such elements occur within a particular area, the soil cover may be radically changed. In addition, these changes become manifest on a global scale.

It is well known that ants building nests in the earth create a biogenic microrelief [10] and affect the properties of the soil. Its density and porosity increase, and the ratio between the pores of different sizes changes. This results in disturbances of the soil water and air regimes in the anthills and their surrounding areas [24]. The anthill pH related observations have proved that alkalization occurs in acidic soils, while acidification occurs in the neutral and alkaline soils [6, 7, 16]; the content of the organic matter increases; its qualitative composition changes [9]; the quantity of the biophilic elements increases [13, 20]; and the microbiological activities change [1, 5, 7, 16]. Therefore, the anthills are examples of the transformations in the soil substrate for a comparatively short period.

The Chernobyl nuclear accident caused radioactive precipitation in the greater part of Ukraine and the adjacent areas. Surveys of different soils that have been carried out in the Russian Federation, Belarus, and Ukraine proved that technogenic radionuclides, such as cesium-137 and strontium-90, in the natural cenoses are tend to accumulate in the leaf litter and the top 5-cm layer of soil [22, 25]. Similar results were obtained in Orenburg oblast [14, 17]. On the arable lands, the layers are mixed. Therefore, the radionuclides are distributed throughout the arable horizon. Their migration into the sublayers is insignificant [11, 12, 17, 25].

Mathematical models have been proposed for assessing radionuclide behavior. They can record the sorption–desorption processes in porous environments, the transfer during filtration, the absorption by grass and tree roots, etc. [8, 18]. The effects of the processes of pedoturbation caused by burrowers, particularly ants, on the profile radionuclide distribution have practically not been studied. The overall distribution of ants of various species in fallow lands, including the areas affected by contamination, allows us to consider them as a factor that can contribute to radionuclide penetration deeper into the soil layers.

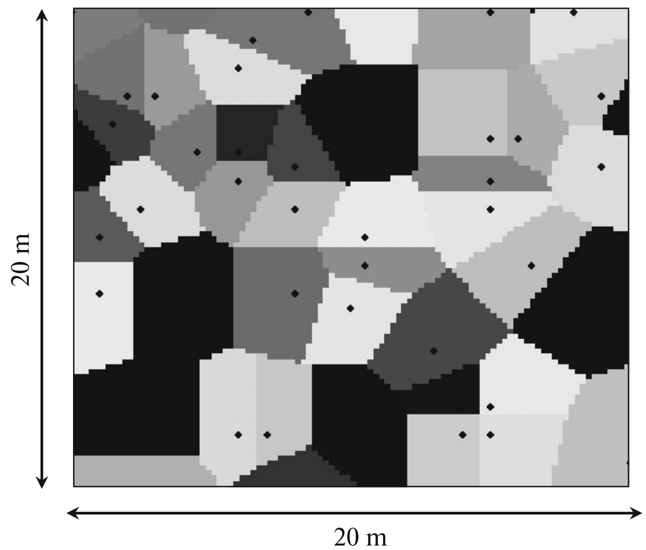

Fig. 1. Voronoi polygons for spatial distribution of anthills.

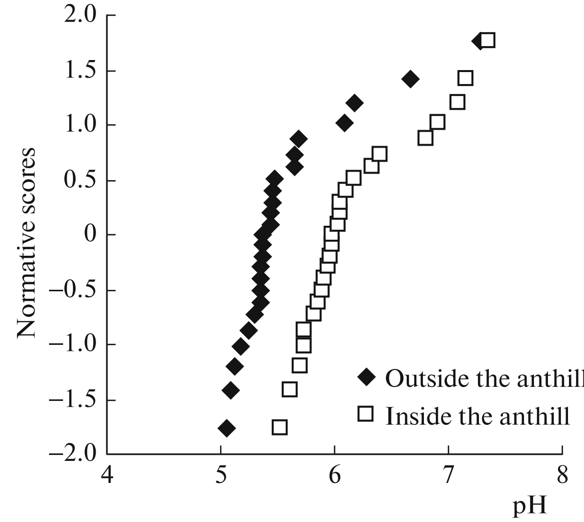

Fig. 2. Normal probability plot for pH levels in area testing.

MATERIALS AND METHODS

The surveys were carried out in fallow land (which had not been cultivated for 15 years) located in Vygonichi raion of Bryansk oblast in June 2015. The area is assigned to the typological group of the Opolie [3]. The relief, which has small saucerlike depressions reaching 5 to 100 m in diameter and a height gradient of 1 to 1.5 m, is rather level. The upper areas are occupied by forest grey soils (agrogrey soils, according to Classification 2004), while the lower land soils are forest grey soil (agrogrey soils) with a second humus horizon, which has a darker color or is nearly black and is typically characterized by lower density and a high humus content. The vegetation includes common reed grass, couch grass, cocksfoot grass, speargrass, red clover, wild vetch, crowfoot grass, bottle-brush grass, burnet saxifrage grass, willow spurge, old man's pepper, common tensy, stinking camomile, artemisia vulgaris and steppe herbs, curley dock, and rarely found undergrowth of birch, pine, aspen, and willow. There are many anthills (up to 0.4 m height) in the area, which are clearly visible in spring, when the ground cover is not expressed yet, while in summer it covers them. The ants are predominantly species of the genus *Formica pratensis* [15, 23].

The number and location of anthills was studied on 20 × 20 m site. The opened anthill was located lower. The soil under an anthill is agro-gray and second humus horizon and crossed by paths with 1–2 cm caverns although the transition from A_{plow} to A_h was clearer.

Soil samples of 1.5 kg weight each were collected at the depth intervals of 5 to 30 and 10 cm to 110 cm in 2 parallel profiles. One of them was under a *Formica pratensis* anthill (0.5 m in diameter), while the other was at the interval of 0.7 m from its center outside the zone of the direct influence.

The pH_{KCl} value, the hydrolytic acidity, the total absorbed bases, the contents of organic carbon (by the Tyurin method) and mobile phosphorus and potassium (Kirsanov's extraction), and the activities of the natural and induced radionuclides ^{40}K, ^{232}Th, ^{226}Ra, and ^{137}Cs were determined spectronomically with the USC Gamma Plus universal complex and the Progress-2000 software suite. The maximum relative bias was 20%. To exclude systematic error, the samples were randomly analyzed.

To compare the acid values for inside and outside the anthills, 25 conjugated samples collected in the dome and at a distance of 25–30 cm from it were collected.

RESULTS AND DISCUSSION

There were 49 anthills on the 20 × 20 m experimental plot. A picture of the area affected by each of them may be obtained using the Voronoi polygon method [2]. The location of the anthills was distributed evently in space. (Fig. 1). The average influenced area was approximately 10 m^2. Therefore, the number of anthills was approximately 1000 units/hectare.

The pH value in the anthills is systematically higher than that in the soil outside them. The values vary on average from 6.17 to 5.56. The 95% confidence interval for the difference comprises 0.61 ± 0.17 pH units, which may show that there are nonrandom differences (Fig. 2). The areal extent of the pH values for inside and outside the anthills differs from the standard. Thus may be a consequence of the local irregularities of the soil cover.

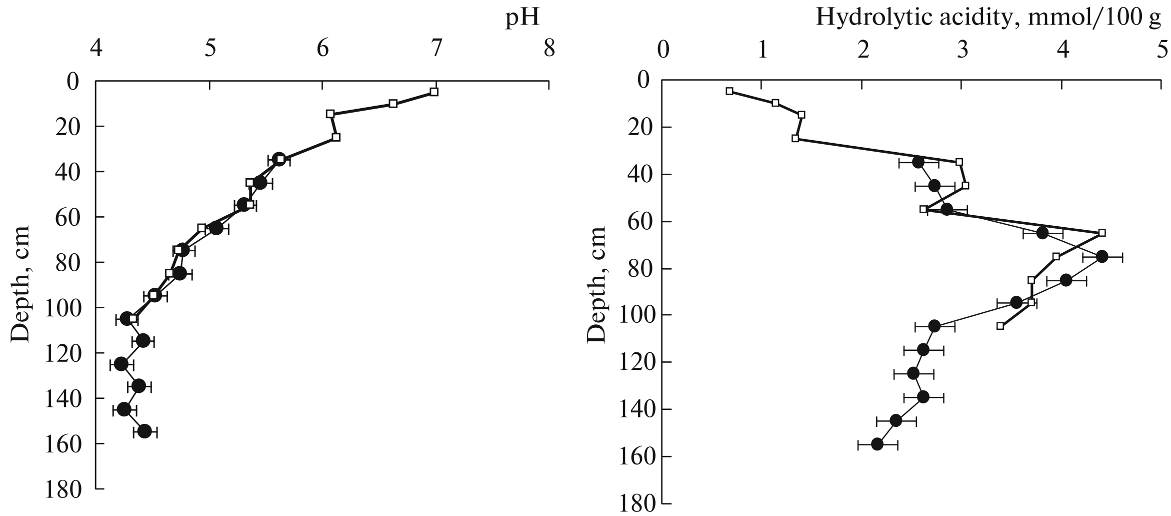

Fig. 3. pH and hydrolytic acidity: ●, soil, □, anthill; segments, 95% confidence interval with respect to the allowed analytical error (here and in Figs. 4–6).

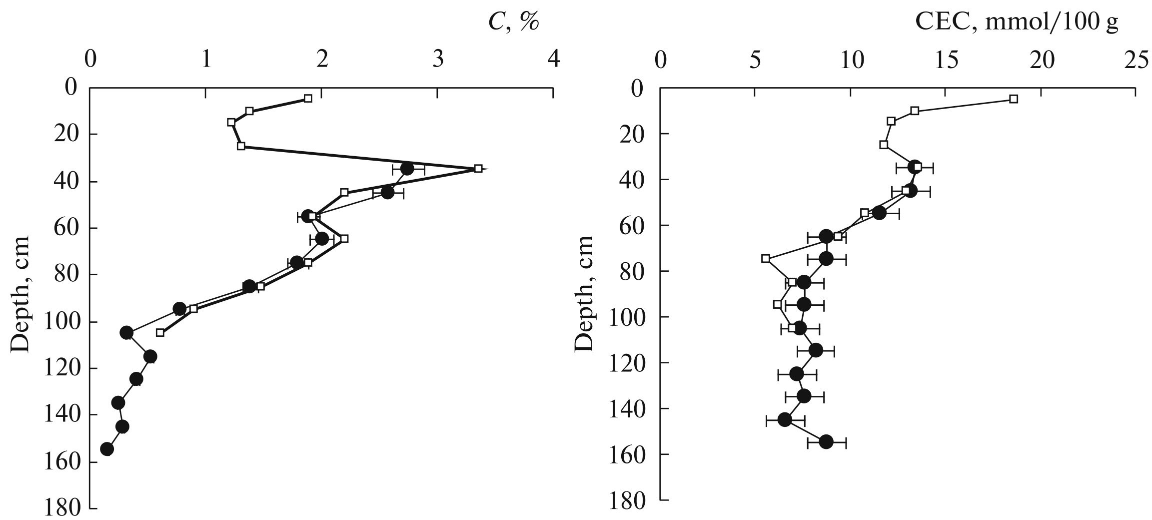

Fig. 4. Organic carbon profile distribution and cation-exchange capacity (CEC).

Analysis of the profiles traversing the anthill and the adjacent soil area shows that the soil mass in the dome has a weak alkaline or neutral environment and a low hydrolytic activity. With respect to the proper soil conditions, the pH value decreases by 0.5 units, while the hydrolytic acidity increases by 1.5 mmol/100 g. The changes in these values with depth are similar for the soil under the anthill and outside it (Fig 3). The arable horizon clearly varies in pH value over the period of lack of the soil treatments. The difference between its top and bottom comes to approximately 0.5 pH units. The second humus horizon can be distinctly distinguished by its hydrolytic acidity values, while the pH_{KCl} values gradually decrease, providing no possibility to distinguish it.

The cation-exchange capacity is greatest in the top 5-cm layer of the anthill. Then, it equals the values in the arable horizon. Afterward, it gradually decreases.

The organic carbon content in the aboveground part of the anthill does not exceed 2%, gradually decreasing with depth. At the level of the soil, a sharp increase is indicated, while afterward a gradual decrease is recorded. The curves for the soil profiles under the anthill and outside it are rather different, while they are practically identical for the lower profile parts. The small increase in the second humus horizon is within the experimental bias. The curves for the

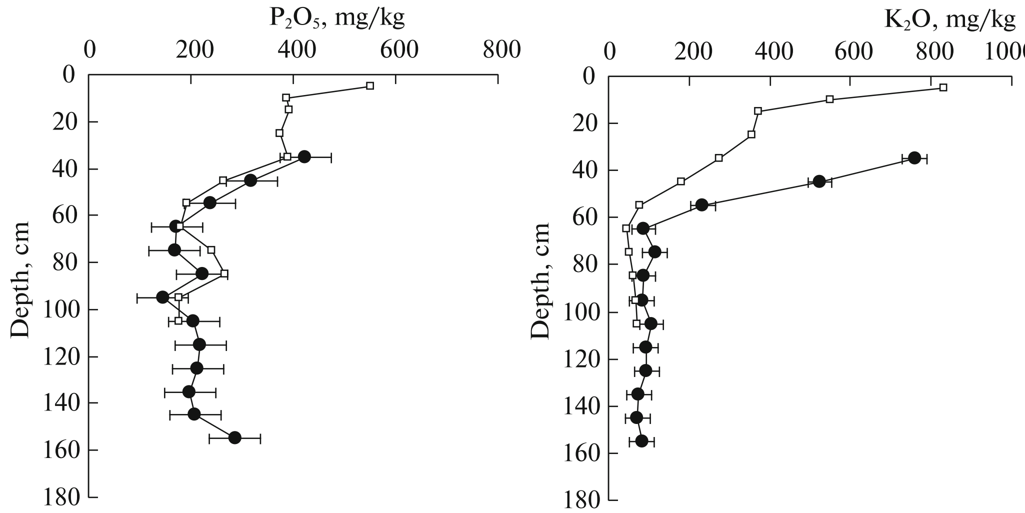

Fig. 5. Mobile phosphorus profile distribution and cation-exchange capacity.

organic carbon content variation and the cation-exchange capacity are very similar (Fig. 4).

The mobile phosphorus content is greatest in the top 5-cm layer of the anthill. It is almost invariable in the deeper layers. Both profiles practically coincide at the ground level and beneath the soil surface. The mobile phosphorus content is great at all depths; i.e., the whole profile appears well supplied with this element. The mobile potassium content profiles start to coincide from the subarable horizon. In the arable horizon, the soil under the anthill contains almost three times less of it (Fig. 5).

The activities of the natural radionuclides (^{40}K, ^{232}Th, and ^{226}Ra) vary up to the depth of 120 cm within the analytical error, showing that there is homogenous soil-forming rock in the area (Fig 6). It is the same in both the anthill and the soil. Attention should be drawn to the fact that the maximum activity of ^{236}Ra is recorded at the depths of 60 to 70 cm both on the profile curve and under the anthill. Although this deviation does not exceed the determination error, the simbitality of the curves can be nonrandom. However, a wider study is required to verify it.

The ^{137}Cs activity decreases with depth, revealing a sudden change with a transition from the arable layer to the second humus horizon. In the deeper layers, its content is practically at the equipment detection limit. Therefore, the confidence interval may cross a value of zero. Under the anthill, the similar sudden change can be observed at the 10-cm lower level.

Thus, the top 10-cm layer of the anthill is quite different from both its sublayers and the soil layers. A neutral reaction of the soil mass, a low hydrolytic acidity, and a high cation-exchange capacity, which significantly exceed the values observed in the soil sublayers, show that this is a result of the ants' living activity, rather than a consequence of the removal of the material out of the soil subsurface horizons to the surface. The soil amount in the anthill dome may comprise no less than 20 m^3/hectare according to assessments of different types. In addition, the upper limit has been assessed as 270 m^3/hectare for chernozems [7]. The first assessment may be more realistic under the conditions of the Bryansk Opolie. However, the scale of the changes in the soil environments under the effect of the ants appeared prominent even in this case. In addition, a shift of the pH values toward alkalization was previously observed [5, 6, 8, 11]. However, the rate of the environmental change under the effect of the ants is rather significant, since the anthills in the analyzed area appeared only after transition from arable land to fallow land, which takes no more than 15 years.

The analyzed soil profiles indicate a clear differentiation of the arable horizon in the carbon contents. Symbasis between the changes in the parallel profiles may prove to be the cause. However, an additional experiment is required in order to understand whether the decrease in the organic carbon content in the arable horizon's lower part is a result of the degradation of humus or, vice versa, the increase in the amount of humus in its upper part due to the development of grass vegetation and the accumulation of organic residues. The loess-type loams in the Bryansk Opolie are rich in mobile phosphorus [19], so that this meter-thick soil may be assigned to the categories for a high or very high supply capacity for this nutrient element. The mobile potassium content is great only at the top part of the profile. The arable horizon tends to vary in phosphorus and potassium content. In addition, if the profiles of phosphorus under the anthill and outside it coincide, a significant difference between the potassium profiles is recorded, which may be also a sign of ant activity.

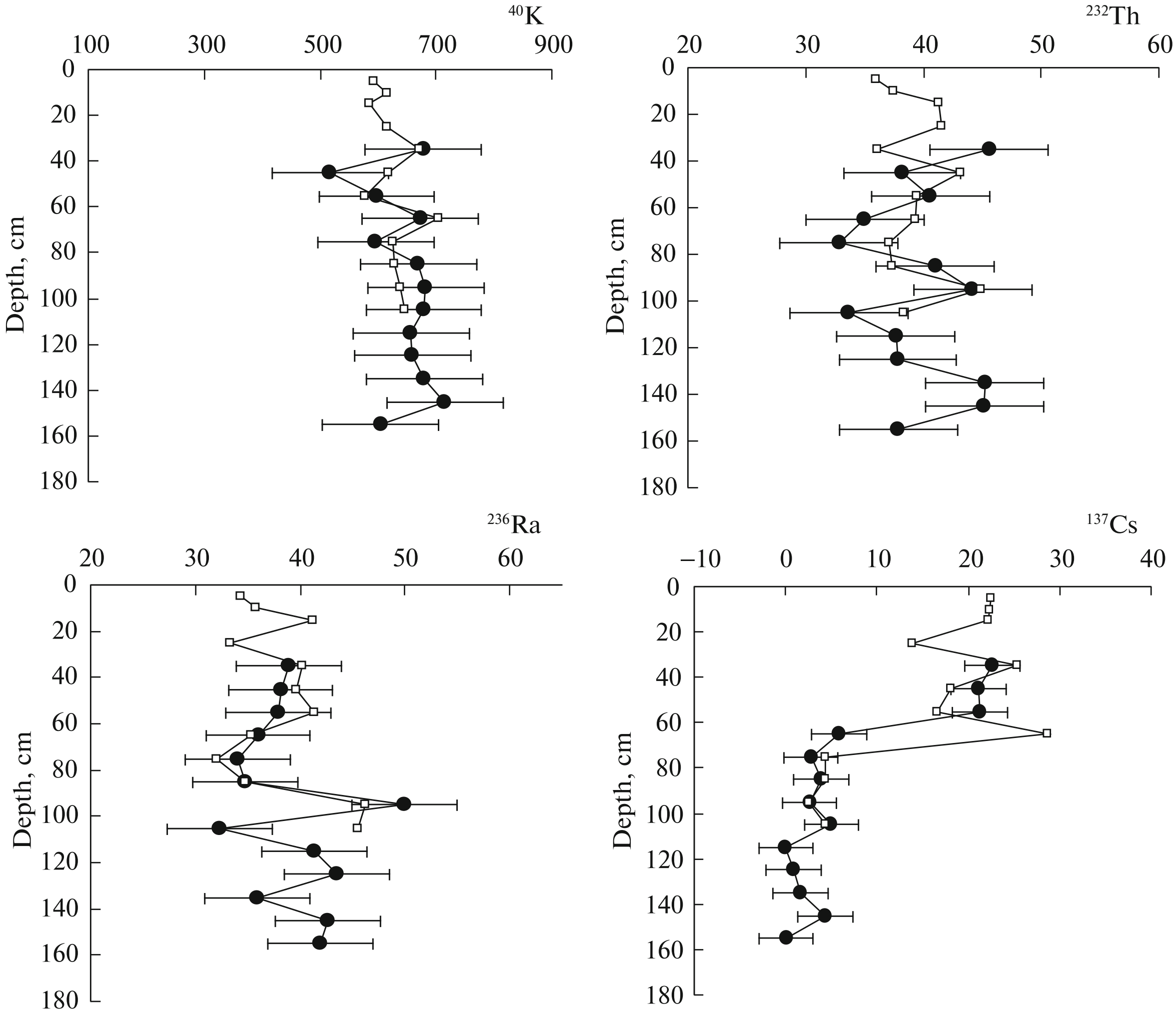

Fig. 6. Radionuclide profile distribution inside and outside the anthill.

Small variations in the natural radionuclide activities in the agrogrey soil profiles may be considered distinctive indications of the identity of the parent rock.

The ^{137}Cs content in the soils of the Opolie before the Chernobyl nuclear accident was approximately 2 Bq/kg. In 1988–1992, the average value increased up to 68 Bq/kg (Bryansk district) [4]. The element activity inside and beside the anthill was approximately 22 Bq/kg. In view of the fact that measurements have not been carried out at the analyzed site and the half-life of ^{137}Cs is 30.17 years, the experiment may be considered to have been completely performed in a region similar to a typical area.

A sharp increase in the radioactive cesium activity at the edge of the arable horizon may show the prevalence of the pedoturbation processes for its migration along the profile. The absence of annual ploughing for 15 years has not resulted in visible cesium migration out of the arable horizon, despite the possibility of migration with the moisture fluxes along the cracks and the plant roots. The processes of pedoturbation caused by the ants' burrowing activities may cause an extension of the depth range of radionuclide high activities under the anthill. This may indicate that the pedoturbation activities of the animals in the soil may be a factor causing technogenic radionuclide migrations in the soil profile. Underestimation of this circumstance, on the one hand, underestimates the speed of their movement within the turbocharged strata, and on the other – overestimates them in the deeper layers.

CONCLUSIONS

A decrease in the acidity of the environments in the anthills located in the Bryansk Opolie fallow land areas covered with grey forest soils has been recorded. That there have been an increase in the humus content and a decrease in the mobile potassium content is clear. These changes took place during the last 10–15 years.

The burrowing activity of ants contributes to the penetration of technogenic radionuclides deeper into the soil. The failure of this circumstance leads to a reassessment of the speed of radionuclide movement in deep layers of the soil and an underestimation of it in the upper part of the profile.

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