The human activities impact on the morphological structure of the landscape soil catenae in different stages of agricultural development of the central black soil region

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Abstract. The studies of the age influence of agricultural development on topogenic soil interfaces were carried out in Belgorod region on two main plots contacting to broad-forest and meadow-stepp zone landscapes of forest steppe. The aim of the study was to assess the impact of agricultural development in different years on the arable soils properties. As a result of field studies, 41 sections were studied in a broad-leaved forest main area (13 sections in the background area, 14 sections each on plowed catenas of different development ages) and 32 sections in a meadow-steppe area (6 sections on background catenas and 12 sections each on plowed catenas). A common pattern characterizing the agrogenic evolution of topogenic soil conjugations in the southern and northern exposures is their progradation into black soils as the use age increases. We have identified the following groups of external anthropogenic factors that directly affect the soil fertility after a long agricultural development: mechanical (pressure on the soil and its treatment with agricultural technology, the creation of micro- and nano-reliefs); organizational and territorial (linear boundaries and forest belts); chemical (applied fertilizers, although in small quantities, but affecting the micro ecosystem of studied areas).

1. Introduction

The essence of the proposed approach to the analysis of soil patterns is to identify in any area one or more model geomorphologic profiles (chains) running from the territory highest point to the lowest one. The profile is graded along the terrain according to individual factors (humidity, temperature, etc.) or a combination of landscape features. The upper parts of the chain are the catena’s driest parts; the lower parts are the wettest. From top to bottom of the catena, most factors sequentially and smoothly change, i.e., in a gradient. Therefore, the catena serves as a mechanism identifying the ecological capabilities of different species of plants, animals, and microorganisms, their combination and ecosystems generally. As noted in the literature [12, 1, 9] changes in many biological parameters (abundance, diversity, biomass of organisms, biological productivity, etc.) along a biogeocenoses number of the same geomorphological profile (catena) are described by bell-shaped curves.

The catena is attractive because it represents the middle link of the landscape structure in terms of scale, intermediate between the elementary cell of the biosphere-the biogeocenosis-and such a large allocation as the landscape. It is a polygon where the soils evolution, the plant cover succession and animal population take place [16, 5].

The catenae practical identification on the location has certain difficulties related to the problem of theoretical models conformity to specific combinations of natural elements.
It should be noted that the term "catena" (translated from Latin it means "chain") has entered the scientific lexicon due to the works of the researcher of the East Africa soils, Joffrey Milne, who made an invaluable contribution to the knowledge of tropical soils [14]. Having studied in detail the soil cover of many parts of Africa, he found that there was no continuous, zonal distribution of one soil type, but there were their natural combinations. He called these combinations catena. It was he who established how individual soils-links in this chain-are connected to each other due to surface and subsurface water runoff.

In Russian literature the definition of the Catena is significantly different from the Western European clear concepts eluvial (no introduction of the substance with the exception of atmospheric precipitation) and accumulative (no out of substance) of the elementary landscapes as a characteristic of the initial and final elements of the Catena [15]. Glazovskaya, M. A. (1983) [3] has added this view the concept of "transit landscapes", which are arranged linearly between eluvial and alluvial and different ratio of supply and removal of nutrients. It is quite obvious that the boundaries between individual elementary landscapes should be drawn according to a set of features, since one of the components of the biogeocenosis may not show important changes, while the others are well delineated during the transition from one elementary landscape to another. The components of ecosystems that are responsive to the change in elevation, include the soil.

The Western European concept of the catena allows for the recognition of any arbitrarily selected part of the slope, while the concept outlined in the Russian-language literature allows for the catena to be considered only the entire slope, since it has only one eluvial and one accumulative landscape. The rest of the landscapes are transitional. If the slope has a complex terrain, then it is possible to distinguish a catena of the first order, and within it - catenas of the second order, each of which has its own eluvial and accumulative elementary landscapes. Examples of studying soil catenae in the south of the forest-steppe from the standpoint of the Russian-language concept approaches are available in the works of a number of scientists [17, 8]. It is their experience that we have applied in this work.

It is known that the relief has a significant impact on soil formation due to the redistribution of substances by different types of runoff. However, these phenomena have not been sufficiently studied, although slopes often occupy much larger areas than leveled watersheds. The question of differences in the moisture content of different parts of the slopes was considered in the works of many researchers, who showed that the soil moisture on the slopes as a whole increases from top to bottom. The reason for the increase in soil moisture on the lower parts of the slopes is considered to be an increase in the runoff layer and an increase in moisture absorption down the slope; however, it is known that a solid layer of water on the soil surface is formed very rarely.

As a rule, the water is concentrated in small lowlands, forming numerous streams. In places of formation of streams, the water is washed away and swam, and the water absorption here does not increase, but weakens, or almost stops. G. I. Shwebs (1974) which indicates that with increasing slope length, the degree of erosion also increases, which leads to a decrease in moisture absorption, and, during the transition from non-washed soils to washed away soil moisture often decreases. Uneven moisture content of different parts of the slope and terrain elements is created due to the redistribution of precipitation along the slope of the warm half-year, the temperature of the surface layer both air and soil, and the unequal consumption of moisture for evaporation.

Soil moisture due to summer rains is also uneven in different locations. Within a limited area, the rains water flows evenly over the entire area, but in the future it is redistributed. On the hills' tops and watersheds, water comes only from the rains, some of it penetrates the soil, some flows down the slopes. On the slopes, rainwater is partly absorbed, partly drains down (down the slope), but here the arrival of water increases in comparison with the tops and upper parts of the slopes due to water flowing from the overlying areas. The inflow of additional moisture on the slopes of the straight and concave profile increases downhill, reaching maximum values at the foot of the slopes and in the valleys. Thus, the redistribution of precipitation in rough terrain is one of the reasons for the differences in moisture reserves in different landforms soils. Moreover, rainwater runoff on the slopes can occur in the absence of its leveled areas.
Agricultural machinery has a very large influence on the rainwater absorption by the soil of the slopes. The essence of agro technical measures on the slopes is to reduce the slope runoff. Plowing across the slope reduces spring runoff by about 3 times compared to longitudinal plowing. The degree of moisture redistribution is influenced by the exposure, the length and shape of the slopes, as well as the amount and intensity of precipitation [6].

2. Materials and research methods
During the study of soils catenary conjugations of the Central forest-steppe, a set of different methods was used. The main ones were: review and analysis of scientific literature (scientific search method), historical and cartographic, field, methods of soil agrogenic transformation, method of laboratory soils analysis, comparative geographical research method.

The historical and cartographic method was used as an information source for the selection of research sites, establishing the age of soils plowing, as well as for mapping arable land of different development ages. To select the first (broad-leaved-forest) research area, we analyzed historical maps, including: "The General Plan of the Belgorod District" (1785), "Military topographic map of the Kursk province" (1864), map V. N. Sukachev (1903), based on which we have selected objects with different history of territory development (Figure 1).

To select the second plot of land, we needed the materials of the Russian state archive of ancient acts (RGADA, Moscow), on the basis of which we installed age agricultural soil studied catenas on meadow-steppe key area of research. The age of the young arable land was 140 years, and the old arable land was 240 years.

![Figure 1. Changes in forest cover on the territory of the Batratskaya Dacha plot and in its surroundings over the past 230 years. The research area is marked by a frame.](image)

The comparative geographical method consisted in a comparative analysis of the background and arable soils properties, as well as arable soils of different plowing ages, and the identification of patterns of their agro-technological transformation.

The method of soil agrogenic transformation was one of the main ones and was based on a comparative analysis of the structure and soil profiles properties on background plots with natural vegetation and on arable land of different periods of agricultural development. The exposure of the slopes (north and south) was also considered.
The field study of soils at the selected main plots involved the following work types: laying of sections, soil description of the soil profiles structure, photographing the front soil sections walls, determination of soil density using steel rings; selection of soil samples for laboratory analysis. Soil samples for analysis were taken within a 2-meter soil profile every 10 cm to a depth of 40 cm and every 20 cm from a depth of 40 cm to 200 cm.

Each soil sample was a mixed soil mass, which was collected at several sites of the section at a similar depth. The soil profiles description was carried out in accordance with the traditional method of soil sections describing. At each known depth point, a sample was taken using steel rings of a known volume in three-fold frequency, and then the average density (volume mass) was determined.

As a result of field studies, 41 sections were studied in a broad-leaved forest main area (13 sections in the background area, 14 sections each on plowed catenas of different development ages) and 32 sections in a meadow-steppe area (6 sections on background catenas and 12 sections each on plowed catenas). Each section was provided with layer-by-layer values of morphometric indicators of soil horizons and the depth of carbonates occurrence.

Methods of laboratory soils analysis have included the addition density determination (volume mass), particle size composition (including the content of the silt fraction) by the Kachinsky method, total humus by Tyurin, and the content of CO\textsubscript{2} carbonates by Tyurin in the Simakov modification. In general, we have examined 380 soil samples taken at the experimental site of the Batratsky Dachas village, and 321 samples from the experimental site of Kurasovka village. All of the above analyses for each sample were performed twice in order to avoid errors in the indicators determination.

The first of the studied sites called "Batratskaya Dacha" is located 20 km from the city of Belgorod, 2 km South-East of the village. Batratskaya Dacha of the Shebekinsky district, Belgorod region (50°34'20"s.; 36°47'50" w. d.). The study objects were arable plots of different ages with an age of agricultural development of 100 and 160 years, respectively. According to the studied cartographic data, we found that before the agricultural development beginning, these areas were occupied by broad-leaved forest. Also, to study the soil changes during the agricultural cultivation influence, the background area under the array of natural broad-leaved forest was studied. We also selected slopes that were similar in length and shape—from a flat watershed to a local erosion base (gulch bottom).

The background forest area consists of two catenas that extend down the gulch slopes of contrasting exposures (South and North). On the gulch bottom there is a common cut for two catenas. In total, 7 cuts were laid on each catena. The maximum slopes steepness in the transeluvial positions was 5-6°. Plots with 100 - and 160-year agricultural development were studied at a distance of 1.5-2 km from the background catenae (Figure 2).
Figure 2. Profiles of catenae used for field research and a satellite image superimposed on the topographical basis of the research area (the site "Batratskaya Dacha").

They represent gulch slopes (areas of 100-year-old plowing), as well as the slopes separating the two gulches (areas of 160-year-old plowing). The surface steepness in these areas did not exceed 5-6°. The shape and length of the inclined arable catenae were selected close to their background analogs. In total, 6-7 sections were laid on each arable catena.

The second study site, Kurasovka, belonging to the meadow-steppe landscape of the forest-steppe, is located on arable land southeast of the Kurasovka village, Ivnyansky district, and the background sites are located near the villages of Safronovka and Pokrovsky, Ivnyansky district, Belgorod region.

These plots were selected by analogy with the conditions for selecting catenas in a broad-leaved forest plot. Their search on the territory of the meadow-steppe landscape of the forest-steppe was the identification of arable soils combinations of the southern and northern expositions slopes with the most characteristic the slopes parameters for the south of Central Russia.

In the catenae identified for the study, the slopes average length was 500-550 m. They are convex in shape and have steepness from 0-2° at the top to 4-6° at the bottom. On each of the four plowed catenas (two polar expositions on the newly developed (140 years of plowing) and on the old-ploughed (more than 230 years of plowing) land), 6 soil sections were laid. All the points of laying of these sections on each catena were selected with the condition that they would have positional analogues on the opposite slope and on the catena’s slopes of a different plowing age (Figure 3).
Figure 3. Profiles of the catenae on which the field research was carried out and the satellite image superimposed on the topographic basis of the research area (the Kurasovka site).

The search for background catenas was accompanied by certain difficulties due to the significant territory development and it was not easy to find soil areas cover untouched by plowing, as well as other types of economic activity. However, such catenae were found not far from the Safonovka villages and Pokrovsky one. Plots were found that were maximally similar in morphometric and morphological characteristics to arable analogues.

On the two background catenae of the northern and southern exposures, 3 sections were laid, the upper of which corresponded to an absolutely flat watershed (a close analogue of the sections 1 locations and 2 on arable land), the middle section corresponded to the positions of sections 3 and 4 on arable land, and the lowest section-the location of sections 5 and 6 in the lower parts of the studied slopes on arable land. The distance between the studied soil profiles of the background catenae was 180-200 m. The limitations of the study points of the background catenae were determined by the weather conditions of the study period, which did not allow them to be studied in detail (by laying 6 soil sections on each background catena).

3. Results and their discussion
A common pattern characterizing the agrogenic evolution of topogenic soils conjugations of the southern and northern expositions is their progradation into black soils as the plowing age increases. This process is particularly noticeable in the catenae soils of the northern exposure, whose 100-year period of operation has already been reflected in the disappearance of the eluvial part of the soil profiles with horizons with the A2 index (A1A2, A1A2B, A2B), and their replacement with horizons A1 and A1B of black soils. In the catena soils of the southern exposure of the 100-year plowing period in the upper part of the catena, signs of eluvial horizons of dark gray forest soils (A1A2, A1A2B, BA2) were still identified.
The above-mentioned horizons of the soil profiles eluvial part were no longer present in the soils of the old-arable catenae (with the age of development of 150 years) of the northern and southern exposure, replaced by the horizons A1, A1B, and BA1 of black soils. The forest past of these soils was only recalled by the texturally differentiated horizons in the region with a nutty structure, cutans and illuviation membranes-directly below the humus profiles of newly formed agrogenic black soils. The most significant transformation of soil morphological features was observed in the lower, most humid part of the slopes, within which the evolutionary transformation of gray forest soils into black soils took place at a more intensive rate.

As for the next physical parameter of soil properties-density, the study was carried out in all catenas at five depths: 5, 20, 55, 90 and 150 cm in three-fold repetition in all soil catenas. We found that the soil density on the plot" Batratskaya dacha" varies in the range of 0.75-1.74 g/cm³. Examples of the distribution of the indicator with depth are shown in Figure 4.

![Figure 4](image)

**Figure 4.** Vertical distribution of soil density on the site "Batratskaya Dacha" (for example, section №3 on three catenas of the northern exposure is taken).

Under the forest, there are the most significant differences in density between the upper and lower horizons. On arable land, due to the increase in density values (the density of the soils of the upper horizons increases from 0.75 to 1.35 g/cm³), these differences decrease. At the same time, it should be noted that the maximum values in the soil densities were recorded in the middle of most sections, which may be associated with the process of search of substances in the middle part of the soil profiles. The minimum values of the density of the upper soil horizons under the forest are not observed anywhere else from the studied catenae on arable land, which is associated with the natural features of the formation of an air-permeable crumbly soil structure here and with the destruction of this structure during plowing.

On arable land, the profile change in the indicator is less contrasting. The minimum values for both young and old arable land were the upper 20 cm. In terms of density, the sub-arable horizons were almost identical to the arable ones, and the differences between them often did not exceed 0.1 g/cm³.

The nature of the radial soil densities distribution differs in different land-use regimes. Under the forest, there are the highest differences in densities between the upper and lower horizons. Thus, the soil density of the upper horizons is only 0.57-0.90 g/cm³, sharply increasing to a depth of 20-30 cm, where the density reaches values of 1.36-1.58 g/cm³. Deeper than 30 cm, the increase in the density of forest soils is more smoothly, reaching values of 1.71 g/cm³.

On arable land, the radial variation of soil densities is noticeably lower. The top 7 cm with values of 1.07-1.27 g/cm³ on 100-year-old arable land and 1.34-1.40 g/cm³ on 160-year-old arable land, currently located under the deposit, were the most loose on both arable land. At the same time, the densities of arable horizons, with the exception of the upper 7 cm, are almost similar to the densities of the sub-arable horizons of the studied soils. Below 7 cm, the variation in soil densities was observed in the range of 1.37-1.58 g/cm³ on 100-year-old arable land and 1.34-1.74 g/cm³ on 160-year-old arable land.
The average soil densities in the soil columns in the watershed areas were: 1.34-1.38 g/cm³ under the forest; 1.40-1.47 g/cm³ on the "young" arable land; 1.55-1.60 g/cm³ on the "old" arable land. One of the most important physical parameters of the soil is the granulated composition. The granulated composition is strongly dominated by the silt fraction. So in the background area at a depth of more than 60 cm, it reaches 50% of the content of all the extracted fractions. The increase in the proportion of silt is also observed to depths of 160 and even 200 cm, which cannot be explained only by a change in the profile nature of the indicator, due to, among other reasons, the search of silt. It is possible that in the studied soils, the granulated composition is also influenced by the soil-forming rock, which contains silt and a dusty fraction to a large extent. At the same time, in the forest there is a more regular (with a gradual growth gradient) pattern of the distribution of silt along the soil profile than in the plowed catenas (Figure 5).

The radial distribution of individual grain size fractions shows a dependence on the type of land use and the duration of plowing. It leads to smoothing of the radial differentiation of the granulometric composition; in particular, the amount of silt particles in the arable horizon increases due to the homogenization of the upper desalinated subhorizons with the underlying, less depleted silt. In the soils of 160-year-old arable land, the alignment of the profile distribution of silt is even more noticeable. In the latter case, the spatial heterogeneity of the granulated composition is strongly expressed, probably due to the increased influence of zoogenic processing of soil profiles (by mole rats).

At the top of the century-old agricultural northern slope (in the first meter of the section), the area of mole rat habitat occupies 18% as on the southern slope. However, in the middle of the catena, there is a sharp change in the picture: the area of mole rat habitat on the northern slope remains equal to 18%, but on the southern slope-the area is reduced to 5-7%, and in some places does not reach 2%. On the second meter of the cut, the number of mole rats decreases and on the two catenae, but the pattern remains. In the north, more humid, it does not exceed 1-2% (Table 1, Figure 6).

On arable land aged 160 years, a similar pattern is observed (Table 2, Figure 7). Moreover, on the old-developed arable land, this pattern is revealed from the very top of the catena.

The area covered by the area of mole rat habitat on the northern exposure, in the first meter of the section occupies the same 18%, but lower down the slope begins to increase to 30%. Whereas on the southern slope, in some sections, the area of mole rat habitat do not stand out at all, or make up 2-3% of the area of the section. On the slope of the northern exposure, the area of mole rat habitat is 6%, and on the slope of the southern exposure - from 1 to 3%.

This pattern can be explained by the fact that on the Northern slope of the feeding base of the mole rat is much larger than on the southern slope, where there is a more rapid drying of moisture, which the plant roots can have a smaller depth distribution and smaller reserves, and on the Northern slope of the evaporation is less intense, which probably leads to an increase in the mass of roots and increase forage for mole rat.
Table 1. Distribution of the area occupied by mole rat habitat in the studied sections arable land 100 years.

| №  | 0-50 | 50-100 | 100-150 | 150+ |
|----|------|--------|---------|------|
|    |      |        |         |      |
| 1  | 8%   | 10%    | 3%      | 1%   |
| 2  | 7%   | 11%    | 2%      | 1%   |
| 3  | 0%   | 2%     | 2%      | 2%   |
| 4  | 1%   | 19%    | 12%     | 9%   |
| 5  | 0%   | 0%     | 14%     | 1%   |
| 6  | 0%   | 0%     | 14%     | 1%   |

100 years of plowing northern exposure

| №  | 0-50 | 50-100 | 100-150 | 150+ |
|----|------|--------|---------|------|
|    |      |        |         |      |
| 1  | 2%   | 14%    | 2%      | 0%   |
| 2  | 3%   | 11%    | 0%      | 0%   |
| 3  | 2%   | 2%     | 3%      | 0%   |
| 4  | 3%   | 6%     | 0%      | 0%   |
| 5  | 0%   | 4%     | 0%      | 0%   |
| 6  | 0%   | 7%     | 1%      | 0%   |

100 years of plowing southern exposure

4. Conclusion

The result of agricultural development of arable land forming the first high density in the soil was detected at a depth of 30-40 cm, which is associated with the phenomenon of "with subsoil soles" – region of the subsurface of the profile to which the pressure is moving across the soil surface objects (farm animals or equipment). Note that this maximum density is also found in the background area; despite the absence of plowing, other factors, such as animal grazing, probably had a compacting effect here in the past.

In the intracatenary fluctuations of soil density, a number of general trends are identified that are characteristic of all the studied catenas. In general, with an increase in the slope steepness from the upper catenary positions to the lower ones, there is an increase in the soil density in the humus and transition horizons. At the same time, the maximum values are observed in the lower links of the catenae, confined to the areas of the slope flattening before the fall, and the increased density values are observed in the upper horizons. Probably, the compaction here on the slopes of the northern exposures is facilitated by the deterioration of the structure, which arose due to signs of coalescence in the humus horizons of the studied soils.

These features were found in the morphological description of the soil profiles in the form of a packed lumpy structure, in contrast to the lumpy, characteristic of the soils of the upper slope.
positions. Merging is possible due to the introduction of Mg cations into the lower links of catenae with soil solutions, the presence of which in the soil absorbing complex leads to the destruction of the structure and the formation of lumpiness.

Table 2. Distribution of the area occupied by mole rats in the studied sections arable land of 160 years.

| №  | 0-50 | 50-100 | 100-150 | 150+ |
|----|------|--------|---------|------|
|    | 160 years of plowing northern exposure | 160 years of plowing southern exposure |
| 1  | 23%  | 4%     | 0%      | 0%   |
| 2  | 14%  | 10%    | 3%      | 1%   |
| 3  | 11%  | 16%    | 5%      | 2%   |
| 4  | 17%  | 31%    | 16%     | 7%   |
| 5  | 3%   | 21%    | 4%      | 0%   |
| 6  | 9%   | 24%    | 2%      | 0%   |
| 1  | 25%  | 7%     | 0%      | 0%   |
| 2  | 0%   | 2%     | 5%      | 2%   |
| 3  | 0%   | 3%     | 3%      | 0%   |
| 4  | 0%   | 0%     | 0%      | 3%   |
| 5  | 1%   | 3%     | 2%      | 0%   |
| 6  | 0%   | 2%     | 4%      | 3%   |
| 7  | 0%   | 0%     | 1%      | 0%   |

Figure 7. Selected, the area of mole rat habitat on 160-year-old arable land Northern exposure A and southern exposure B.

Also, an increased density is observed in the soils of the catenae middle links of the insolated slopes. Presumably, it is caused by the manifestation of erosion processes, due to which the denser layers of the soil-forming rock approach the surface.

The initial heterogeneity of the soil-forming rocks contributes to the radial distribution of the granulated composition. In the background areas with depth, there is a gradual weighting due to an increase in the proportion of the silt fraction, which may be due to the presence of light-clay underlying rocks, which are replaced closer to the surface by less heavy brown carbonate loams.

The granulated composition in the area with arable soils is uniform in the vertical profile of the soil. Against this background, the processes of movement of silt fractions in the upper part of the profile, which arise due to siltation, are noticeable.
Studying the morphological features of the soil in the studied areas, we found certain patterns in the distribution of fresh areas of mole rat habitat found in the soils of the plowed catenas. They are defined by clear contours and loose filling. Thus, we found that on the slopes of the northern exposure, the area occupied by the area of mole rat habitat is much larger than the area under them on the walls of the sections of the southern expositions. This pattern can be traced both on young and old-age arable land.

In the soil sections studied by Catena, we identified numerous mole rats and shrew holes. Especially many of them were found at a depth of up to one meter, which is often also reflected in the minimum density of the soil at this depth. The average area occupied by the area of mole rat habitat on the walls of the average section is 80-90% on young arable land and 70-80% on old-aged land. At the same time, in the soils of the background catenas, the mole rats left not so many traces as on arable land. According to the average characteristic, only 30-40% of the soil sections walls were occupied by the area of mole rat habitat against the background.

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