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GENESIS AND GEOGRAPHY OF SOILS

Trends of the Natural Evolution of Chernozems on the East European Plain

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Abstract—A generalized chronosequence of changes in the morphometric parameters of chernozems in the past 5100 years is analyzed. It is shown that the development of chernozems in the center of the East European Plain is characterized by both long-term (interglacial, encompassing the entire Holocene) and short-term (within separate climatic periods of the Holocene) trends. The long-term trend of the evolution of ordinary chernozems developed from the loess-like calcareous loam consists of a continuous increase in the thickness of the soil humus profile and an oscillating increase in the depth of the carbonate accumulations. The Late-Holocene short-term trends of the natural evolution of chernozems are characterized by the high spatial heterogeneity related to the patterns of climatic fluctuations and to the lithological composition of parent materials. In that period, the thickness of genetic horizons in the forest-steppe chernozems was increasing faster than that in the steppe chernozems.

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INTRODUCTION

The appearance and development of the area of chernozemic soils was one of the major events in the Holocene evolution of the biosphere. The Eurasian area of chernozems occupies a special place in the history of human society, as well as in the history of soil science; its meaning in the modern realities of the development of our civilization can hardly be overestimated. Among various aspects of the study of these soils, the problems related to the mechanism of transformation of the major properties (including the humus status) of chernozems and to the regional trends in their development are particularly significant. The strategy of sound management and sustainable agricultural development of these soils should take into account the natural trends of their evolution. The regional specificity of the Holocene evolution of Eurasian chernozems has been shown in many works [3, 7, 9–11, 17, 20, 25, 31, 32, 34].

Important generalizations concerning the evolution of chernozems in space and time have been performed by Aleksandrovskii [1, 2], Aleksandrovskii and Aleksandrovskaya [4], Ivanov [12], Ivanov and Demkin [13], Ivanov and Lisetskii [14], Ivanov [11], Ivanov and Tabanakova [15], and Chendev and Ivanov [33].

In this paper, we consider the Holocene evolution of chernozems with a particular emphasis on the following aspects:

—the analysis of the long-term (interglacial, full-Holocene) trend of the development of chernozems on the basis of data on a comprehensively investigated chronosequence of ordinary chernozems and

—the characterization of the regional specificity in the development of the profiles of forest-steppe and steppe chernozems in the center of the East European Plain in the Late Holocene.

TRENDS IN THE DEVELOPMENT OF CHERNOZEMS DURING THE MODERN INTERGLACIAL STAGE OF THE QUATERNARY PERIOD

The first mathematical models describing the soil development with time suggested that the changes in the soil properties follow an exponential law [35]. Later, the models of a heterochronous realization of the exponential development of the soil features within the same soil profile were suggested [29], the notions of soil self-development and soil evolution were introduced [2], the polygenetic and polyclimax nature of soil profiles was examined [28], and the concepts of statopedogenesis and mutapedogenesis were developed [6, 7] in order to describe the complicated character of the soil evolution. The further work of Russian pedologists in this field was concentrated on the study of particular soil chronosequences in the forest-steppe, steppe, and semidesert zones of the East European Plain and the Southern Ural region. The

Table 1. Temporal changes in some morphological features of ordinary chernozems in the center of the East European Plain, % of the modal values in the modern chernozems (according to the data from Aleksandrovskii [2, 3], Zolotun [10], Ivanov [12], Pesochina [23, 24], and Chendev [32])

Parameters of the soil profile	Time (years ago) and the number of soil objects studied for each particular chronosection (*n*)														
	5100 (1)	4750 (1)	4580 (1)	4500 (1)	4300 (1)	4130 (1)	4000 (3)	3750 (1)	3600 (1)	3400 (1)	2900 (4)	2400 (1)	1900 (3)	1150 (1)	0
Thickness of the horizons:															
A1	58	37	55	40	44	54	39	43	54	42	71	114	75	93	100
A1B	50	178	61	161	56	130	111	83	83	116	105	67	161	67	100
A1 + A1B	56	75	56	72	48	74	57	55	62	63	80	102	99	86	100
B	83	40	83	77	89	100	48	150	103	55	62	126	120	50	100
BC	162	171	112	106	124	109	103	53	94	91	75	86	68	81	100
entire profile	90	90	77	82	78	90	67	80	81	67	74	105	96	75	100
Depth of															
effervescence from HCl	93	68	100	68	67	57	62	68	83	54	54	100	101	100	100
upper boundary of calcareous nodules	>172	106	56	92	78	83	62	Abs.	112	95	Abs.	160	94	78	100

Note: Abs. means the absence of data.

Holocene evolution of soils was considered as the cyclic dynamics of soil features and processes of different intensities without definite trends in their development on the Holocene time scale [1, 4]. However, soil scientists were also interested in revealing the general temporal trends in the character of pedogenesis. An attempt to describe the Holocene trends in the development of humus profiles of zonal soils on the East European plain with the use of the Gompertz exponential function was made in the works of Lisetskii [19] and Goleusov and Lisetskii [8].

From our point of view, the use of the modern interglacial period (Holocene) for revealing the major trends in the development of soils is quite justified. The probability of definite long-term Holocene trends in the development of chernozems was supposed by Gennadiev [7] and Ivanov [11, 12]. During the defense of the doctoral dissertation by A.L. Aleksandrovskii, V.O. Targulian noted that mature zonal soils should change considerably in several thousand years; i.e., the future soils will differ from the soils that are studied by us at present even in the case of stable climatic conditions. Ongoing changes in the soil properties take place in the entire vadose zone and gradually accumulate with time.

At present, the most complete information about the Holocene evolution of chernozems is available for ordinary chernozems developing under automorphic conditions from the loess-like loams in the center of the East European Plain. A generalized chronosequence of temporal changes in the properties of these soils encompasses the past 5100 years and consists of 15 particular chronosections for the second half of the Holocene. Table 1 contains data on the morphometric characteristics of the chernozems of different ages (in percent of their values in the modern chernozems). Figure 1 displays these data in absolute values (centimeters). The paleochernozems buried under kurgans of different ages were studied in various parts of the steppe zone and included the following chronosections: 5100, 4750, 4500, 3750, 3600, and 3400 BP for Dnepropetrovsk oblast [12]; 4580 and 4130 BP for Voronezh oblast [2, 3]; 4000 BP for Dnepropetrovsk, Voronezh, and Rostov oblasts [12, 23, 24, 32]; 2900 BP for Zaporozhskaya oblast [10]; 2400 BP for Rostov oblast [23, 24]; 1900 BP for Dnepropetrovsk and Rostov oblasts [12, 23, 24]; and 1150 BP for Belgorod oblast (unpublished data by Yu.G. Chendev).

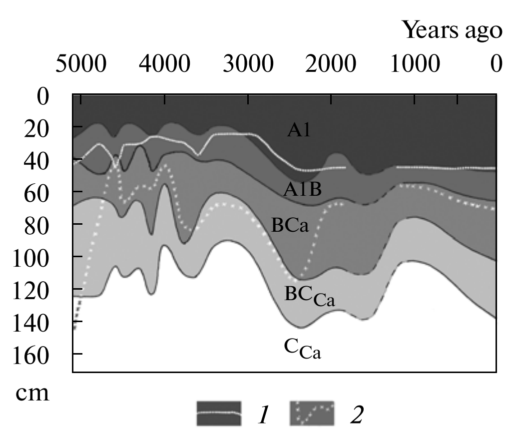

Fig. 1. Changes in the morphology of the profiles of ordinary chernozems in the center of the East European Plain during the past 5100 years (a generalized scheme): (*1*) the line of effervescence and (*2*) the upper boundary of the calcareous nodules (according to the data summarized in Table 1).

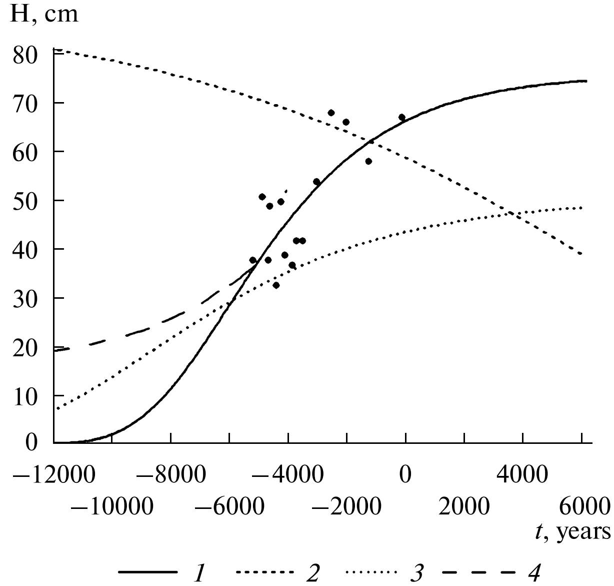

Fig. 2. Hypothetic trends of changes in the properties of ordinary chernozems during the modern interglacial period (on the time scale, 0 corresponds to the present time): (*1*) the thickness of the humus profile, (*2*) the thickness of the lower part of the soil profile (B + BC), and (*3*) the depth of the effervescence. Curves *1*, *2*, and *3* are described, respectively, by the following exponential equations: $H1t = 75\exp(-\exp(-1.948 - 0.000327t))$, $\eta = 0.765$; $H2t = 90\exp(-\exp(-0.828 + 0.00011t))$, $\eta = 0.315$; $H3t = 50\exp(-\exp(-1.837 - 0.000212t))$, $\eta = 0.426$. The circles indicate the factual (determined) values for the past 5100 years. Curve *4* indicates a different model of the changes in the thickness of the humus horizons.

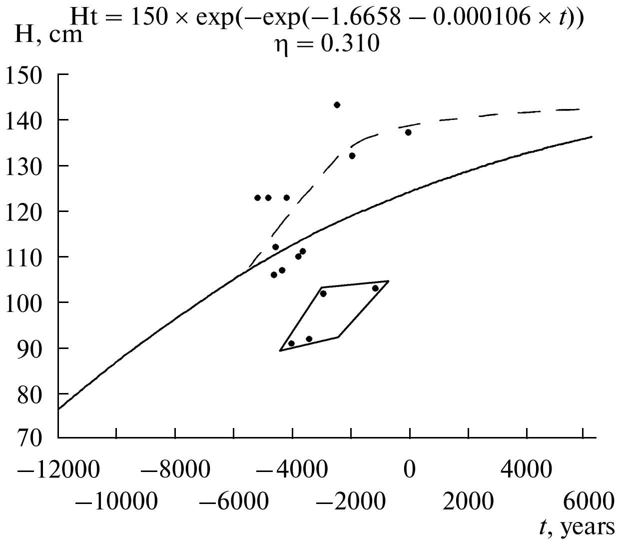

Fig. 3. Hypothetic trend of changes in the thickness of the profile of ordinary chernozems during the modern interglacial period. The circles indicate the factual (determined) values for the past 5100 years. The extreme values are encircled (with a rhombus). The dashed line indicates a different model of the interpretation of the results.

This chronosequence (Table 1, Fig. 1) attests to the rather complicated dynamics of the morphometric characteristics of chernozems with time. Changes are observed not only in the humus profile but also in the deeper horizons (including the BC horizon) and reflect the general tendencies in the development of these soils. At the same time, though we used relative values (% of the values in the background surface soils) and various recalculations, the obtained model surely contains some "noise" related to the spatial variability of the soils. This "noise" was unavoidable. Moreover, it was impossible to build the model on the basis of the initial data on the morphometric soil characteristics in absolute values (depths of different soil horizons in cm).

The sharp variability in the lower boundaries of the Bca and BCca horizons and, partly, of the A1 and A1B horizons; the coincidence of the maximum depth of effervescence and the high position of carbonate accumulations in the soils that existed about 3200 BP; and several other characteristics are particular examples of the noise factor. At the same time, we can see a number of important tendencies: good agreement between the changes in the thickness of the humus horizons and the depth of the carbonate horizon for the period from 4700 to 2000 BP, a sharp change in the soil properties at about 3200 BP, and good agreement between the depth of the effervescence and the depth of the carbonate concentrations for the last 2000 years. Some of these tendencies were unknown before our study and require special interpretation.

Figures 2 and 3 display the long-term trends of changes in the thickness of the separate genetic horizons and in the entire soil profile and in the depth of effervescence for the ordinary chernozems. The initial data were obtained during the morphometric study of the soil profiles included in the considered chronosequence; the changes in the depths of effervescence were calculated as deviations (in cm) from the corresponding average depth in the background surface chernozems. The Gompertz function was used to describe these changes. It was found that this function belonging to a group of S-shaped growth curves ensures the best fit of the model to the factual data on various soil processes [8]. The corresponding model was developed for the time period from the beginning of the Holocene to the present time and extended 6350 yrs into the future. The latter date was selected as the probable beginning of the new glacial epoch according to Maksimov [21], though there are different opinions on this matter: from 4000 years according to Khotinskii [30, 32] to 10000 years according to Berdnikov [5] and 23000 years according to Imbrie [16].

As seen from these figures, the nonlinear estimate (η) has a maximum for the indices of the thickness of the humus profile of the chernozems (strong correlation); the exponential models for other soil characteristics (depth of effervescence, thickness of the lower horizons, and total thickness) have a low or medium

Table 2. Average morphometric characteristics of the soil subtypes in the center of the East European Plain in the modern epoch and 3000–3500 years ago for the zonal sequence from leached chernozems to chestnut soils

Indices	Modern soils					Soils that existed 3–3.5 ka ago in the place of modern subtypes of chernozems				
	CHl	CHt	CHo	CHs	K	CHl	CHt	CHo	CHs	K
	thickness, cm					% of the modern values/the calculated thickness, cm				
A1 + A1B	67	93	63	55	41	74/48	79/73	61/38	62/34	77/32
Total thickness of the profile (A–BC)	134	167	150	122	94	80/107	85/142	83/124	95/116	83/78
Depth of effervescence, cm	113	68	56	53	39	40/45	55/36	56/31	74/39	94/37
Upper boundary of the $CaCO_3$ concentrations	113	75	75	80	54	40/45	67/50	73/55	80/64	94/51
Upper boundary of the gypsum concentrations	>200	>200	>200	200	160	>200	>200	160	160	160
Number of studied soils	30	50	55	266	31	3	4	12	7	2
Soil subtypes 3–3.5 ka ago	–					Intergrade between CHt and CHo		CHs	K	

Note: The soils are classified according to the *Classification and Diagnostics of Soils of the Soviet Union* (1977); CHl—leached chernozems, CHt—typical chernozems, CHo—ordinary chernozems, CHs—southern chernozems, and K—chestnut soils.

correlation with the factual data and may be considered just as tendencies.

The initial thickness of the humus horizon of the initial soil at the zero-moment of the Holocene pedogenesis (10000 BP) may be taken equal to 20 cm [11, 12]. The curve describing the temporal changes in this parameter has an S-shaped character (Fig. 2). The total thickness of the initial soil profile was taken equal to 75 cm (Fig. 3). The depth of effervescence in the initial soil was close to the soil surface. The thickness of the B horizon generally decreases with time at the expense of the increasing thickness of the A1 + A1B horizons (Fig. 2). The curve describing the general increase in the thickness of the entire profile (Fig. 3) has two characteristic bends corresponding to the soils that existed 2000 and 4000 BP. These bends against the general trend toward an increase in the thickness the soil profile indicate that the development of the latter was somewhat slower than could be supposed on the basis of the data extrapolation.

The revealed tendencies of the temporal changes in the depth of carbonate accumulations (i.e., in the rate of carbonate leaching) and in the decreasing thickness of the lower soil horizons (B + BC) at the expense of the increasing thickness of the upper (A1 + A1B) horizons deserve special consideration. The latter tendency attests to the progressive development of humus accumulation in the chernozems during the Holocene.

It should be stressed that these conclusions have a preliminary character because of the low amount of factual data in the basis of our models. However, the idea of modeling the dynamics of the soil morphometric characteristics, including the characteristics describing the dynamics of the soil carbonates, seems to be interesting and promising.

CLIMATIC TRENDS OF THE DEVELOPMENT OF CHERNOZEMS IN THE LATE HOLOCENE

The asynchronous character of the development of the zonal soils in the forest-steppe and steppe zones of the East European Plain at the end of the Subboreal period was already noted in our earlier publications. The Subboreal aridization of the climate in the steppe and forest-steppe regions began at approximately the same time; however, it was longer in the steppe zone [15], which resulted in the more active development of the humus profiles of the modern chernozems in the forest-steppe chernozems in comparison with the steppe chernozems [32]. Recently, we analyzed the published materials and our own data to calculate the morphometric parameters in the zonal sequence of soils developing from the loess-like calcareous loam—from leached chernozems to southern chernozems and dark chestnut soils—at the end of the Subboreal period (3500–3000 BP); overall, 21 soil objects were analyzed (Table 2). The studied area is limited by latitudes 51°N–46°N and by longitudes 35°E–37°E. It extends 800 km to the south of Kursk toward the Sivash Bay of the Sea of Azov.

We have revealed certain differences in the degree of contrast between the properties of the modern soils and the paleosols that existed in the same areas 3500–3000 BP. Thus, the difference in the thickness of the humus horizons in the modern soils of the studied region reaches 52 cm (from 41 cm in the chestnut soil to 93 cm in the typical chernozem); in the paleosols of the Subboreal period, it did not exceed 41 cm. The difference in the total thickness of the modern soil profiles (A–BC) reaches 73 cm; in the paleosols, it was somewhat less (64 cm). In general, the direction of the evolutionary changes in these soil properties has been the same in different parts of the studied region. However, as a result of these changes, the differences in the thickness of the humus horizon and the entire soil profiles in the modern zonal soil sequence are more considerable than those that existed about 3000 BP.

The changes in the depth of the accumulation of carbonates and gypsum in the studied soils have been less contrasting. In the modern zonal soil sequence, the differences in the depth of the line of effervescence and in the depth of the calcareous nodules reach 74 and 59 cm, respectively; in the paleosols, they did not exceed 14 and 19 cm, respectively. The paleosols of the Late Subboreal period were characterized by relatively stable pools of carbonates in the 2-m-deep thickness [26]. At the same time, the difference between the depths of the horizons containing gypsum in these paleosols was rather considerable. The lower boundary of the humus layer (A1 + A1B) and the upper boundary of the horizon with carbonate concentrations almost coincided in the Subboreal paleosols, except for the soils that existed in the place of the modern typical chernozems. In these paleosols, the thickness of the humus layer reached 73 cm, and the depth of the horizon with carbonate concentrations was 36 cm (at present, 50 cm).

Tendencies of soil changes in the past 3000–3500 years. After the Subboreal period, the thickness of soil humus horizons increased by 20–25 cm in the chernozems and by about 10 cm in the chestnut soils. The A1B horizon of the modern chernozems was shaped from the Bca horizon in the past 3000–3500 years; the carbonates have been leached off from this horizon. The illuvial horizons of the modern leached chernozems were also shaped in the same period. The illuviation of substances and the formation of cutans in the B horizon of these soils took place after the leaching of carbonates.

The leaching of carbonates has been active in the chernozems; the depth of the effervescence has increased by 70 cm in the leached chernozems and by 20 cm in the southern chernozems. In the chestnut soils, it has been relatively stable. The same tendency has been noted for the lowering of the upper boundary of the horizon containing carbonate concentrations. The reserves of calcium carbonates in the 2-m-deep soil layer have been subjected to minimum changes, though the distribution pattern of the calcium carbonates in this layer has changed [12, 24]. Gypsiferous pedofeatures have been dissolved and removed beyond the 2-m-thick layer in the ordinary and southern chernozems; in the chestnut soils, they have not changed their position in the profile. In the southern and ordinary chernozems, the pseudomorphic substitution of calcium carbonates for gypsum has taken place. The entire thickness of the soil profiles has increased by 20–25 cm. The reserves of total (organic + mineral) carbon in the steppe soils have been relatively stable [24, 25].

Classification of paleosols dating back to 3000–3500 BP. The classification position of the studied paleosols (according to the classification system of 1977 [18]) can be determined on the basis of data on the thickness of humus horizons (A1 + A1B), the depth of effervescence and carbonate accumulations, the depth of gypsum accumulations, and the presence of some illuviation features (in the leached chernozems). Our study indicates that the soils occupying a transitional place between typical and leached chernozems existed in the areas of modern leached and typical chernozems at the end of the Subboreal period (3000–3500 BP), southern chernozems existed in the area of modern ordinary chernozems, and chestnut soils existed in the areas of modern southern chernozems and dark chestnut soils. The most considerable changes in the past 3000–3500 years have taken place in the area of modern leached chernozems; the minimum changes have taken place in the area of modern chestnut soils.

Two factors specifying these changes should be mentioned. First, the aridity of the climate in the preceding period (4200–3900 BP) was higher [4, 15, 27] and favored the development of more arid soils. Some cooling and humidization of the climate after that period led to the more contrasting differentiation of the climatic conditions in the studied region and, hence, to the more considerable differentiation of the modern soils. The most active transformation of the soil cover took place in the interval from 3900 to 2500 BP [11, 15]. The time factor is also important. The soil evolution in the past 3000 years has resulted in the formation of well-developed modern soils; the degree of their development is higher in comparison with that in the paleosols that existed in the studied area in the previous epochs of the Holocene.

LITHOGENIC TRENDS IN THE DEVELOPMENT OF CHERNOZEMS IN THE LATE HOLOCENE

The specificity of the Late Holocene trends of the development of the chernozems was controlled not only by the geographic position of the particular soil zones but also by the lithological factors. This is clearly seen from the results of the study performed by us at two key sites in Belgorod oblast (the Belgorodskii and Prokhorovskii key sites). Let us consider the major regularities of soil evolution at these sites in the Late Holocene.

The Belgorodskii key site. The paleosols buried under two kurgans of the Srubnaya cultural epoch (3500–3000 BP) were studied on the interfluve between the Severskii Donets and Toplinka rivers in the southern part of Belgorod oblast (Fig. 4). The kurgans were located at a distance of 80 m from one another. Geomorphologically, the studied plot represented a relatively narrow (250–300 m) elevated flat area separated by slopes of local flat-bottomed gullies (balkas). The thickness of the surface layer of loess-like loams on the flat part exceeded 3 m. Combinations of typical and leached chernozems were described on the flat area and on the surrounding watershed slopes. The bodies of the kurgans consisted of the upper parts of the humus horizons of the paleochernozems excavated from the trenches encircling the kurgans. The relative height of the lower kurgan at the time of our study was 0.5 m, and the height of the higher kurgan was 1.1 m. According to the topographic maps developed in the middle of the 20th century, the height of these kurgans at that time was two times greater. The lowering of the kurgans was due to the intensive plowing of the territory in the second part of the 20th century.

Medium-deep calcareous typical paleochernozems were described under both kurgans; their morphometric properties (the depths of the major horizons, including the depth of the horizon with carbonate concentrations) were approximately similar. However, these paleochernozems differed from one another in their textural characteristics, the degree of zoogenic processing of the soil mass, and the distribution patterns of carbonates.

The paleochernozem buried under the larger kurgan had a generally heavier texture and a lower degree of zoogenic processing in comparison with the paleochernozem under the smaller kurgan.

In the latter soil, the carbonate concentrations in the middle-profile horizons (from the lower part of the [A1] horizon to the [BCca] horizon) were represented by pseudomycelial forms and by thin films (calcareous mold) in approximately equal proportions (the films were mainly concentrated in mole tunnels). The maximum content of these forms of carbonate concentrations was observed in the [A1Bca] and [BCca] horizons. In the parent material, only calcareous mold was present. In the paleochernozem under the large kurgan, the distribution of carbonates had a different pattern, though the line of effervescence in both paleosols was at the same depth (25 cm from the buried paleosol surface). The carbonate concentrations in this paleosol were less abundant, the distribution of calcareous mold had a localized pattern, and the amount of calcareous pseudomycelium was smaller. No horizon with a distinct maximum of carbonate concentrations could be distinguished. In the parent material, thin pseudomycelial and film forms of carbonate concentrations were present. From the depth of 150 cm, local concentrations of silicified calcite were observed (these features were absent under the small kurgan).

The background surface soil near the small kurgan was classified as a medium loamy deep typical chernozem. The background surface soil near the large kurgan was classified as a medium to heavy loamy medium-deep leached chernozem. The differences between these two background soils represent a typical example of the spatial variability of soil features.

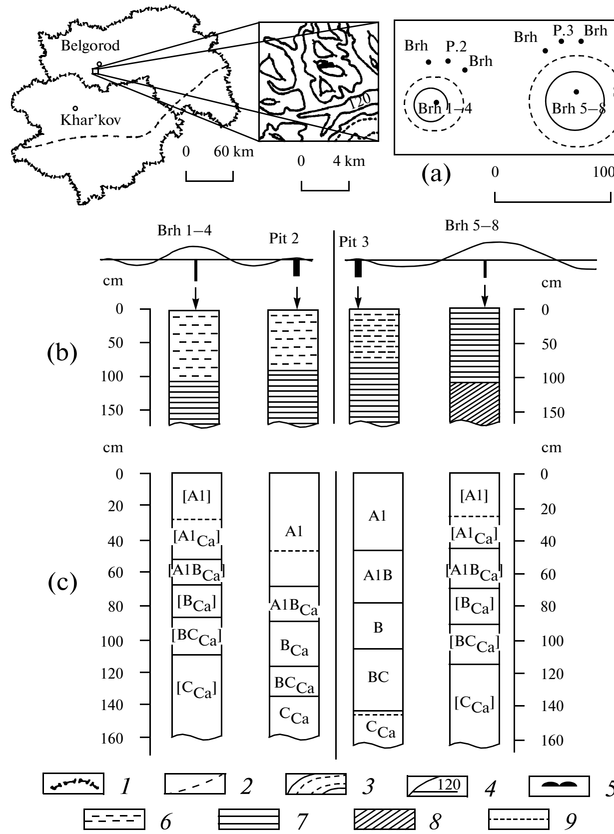

Fig. 4. Scheme of the Belgorodskii key site (a) and the properties of the studied soil profiles: (b) the soil texture and (c) soil horizonation. Designations: (*1*) the administrative boundaries of Belgorod and Khar'kov oblasts, (*2*) the boundary between the forest-steppe and steppe zones, (*3*) contour lines (the contour interval is 40 m), (*4*) the minimum absolute height, m (multiple of 10), (*5*) the location of the studied kurgans, (*6*) medium loam, (*7*) medium to heavy loam, (*8*) heavy loam, and (*9*) the line of effervescence.

In the past 3500 years, the thickness of the humus layer (A1 + A1B) in the background chernozem near the large kurgan has increased by 10 cm, and the thickness of the lower soil horizons (B + BC) has increased by 21 cm. The entire thickness of the soil profile has increased by 30 cm. The structure of the B horizon has been transformed from small blocky to medium blocky (with elements of a crumb structure), and thin dull organomineral films have appeared on the surface of blocky peds. The considerable differences in the distribution of carbonates between the soil profiles studied in pit 3 and in borehole 5–8 (Brh 5–8, Fig. 4) seem to be abnormal. We failed to find an analogue to the soil sampled in borehole 5–8 within the adjacent area. Certainly, there are no reasons to suppose that the soil texture in pit 3 has become coarser (in comparison with that in the buried paleochernozem) in the past 3500 years.

The study of the background surface soils near the small kurgan attests to a somewhat different pattern of the soil evolution in the past 3500 years. The depth of leaching of carbonates (from 23 cm to 45 cm) was smaller, and the increase in the thickness of the humus layer is more considerable than the increase in the thickness of the lower (Bca and BCca) horizons (Fig. 4).

The difference between the patterns of the evolutionary changes in the two soils studied at this site may be explained by the natural difference in the lithological conditions: the soil in the area of the small kurgan is developed from a somewhat coarser material with a higher content of calcium carbonates in comparison with the soil in the area of the large kurgan. The lower initial content of calcium carbonates in the latter soil may be the major factor that favored a deeper leaching of carbonates in the Late Holocene.

The Prokhorovskii key site. A kurgan of the Late Bronze Age (the Srubnaya culture, 3000–3500 BP) was studied in the upper reaches of the Severskii Donets River on the interfluve between the main river channel and its tributary (the Sazhnovskii Donets River). This territory is composed of a relatively thin layer of calcareous loess-like loam underlain by the Neogene and Quaternary clayey and loamy sediments containing some amounts of soluble salts. Combinations of typical and leached chernozems are developed on the watersheds and watershed slopes, and more complex combinations of leached chernozems and solonetzic chernozems with eroded variants of these soils are found on steeper slopes in places with shallow embedding by the salt-bearing substrates.

The background surface soils were studied in two pits on a flat surface at a distance of 40–50 m from the kurgan. In pit 1, the profile of a medium loamy deep typical (close to leached) chernozem was excavated (Ap + A1 = 63 cm; Ap + A1 + A1B = 88 cm). The effervescence was observed from the depth of 90 cm. In pit 2 (135 m to the southwest from pit 1), a medium loamy medium-deep leached chernozem was described (Ap + A1 = 58 cm; Ap + A1 + A1B = 75 cm). The depth of effervescence in this soil was 108 cm. The carbonate concentrations in the background soils were represented by pseudomycelial forms; coarse calcareous nodules were present in the parent material.

The paleosol under the kurgan was studied in two archaeological excavations. It was classified as a medium-deep typical chernozem and had the following morphometric characteristics: [A1] = 35 cm; [A1 + A1B] = 57 cm; and the depth of effervescence = 35 cm. Carbonate concentrations were represented by the pseudomycelial and thin film forms. The profile of this paleochernozem had some solonetzic features. Thus, the lower part of the humus horizon had a coarse blocky structure with the compact arrangement of aggregates and with dull films on ped faces. However, the results of the chemical analyses indicated that, at the time of the kurgan's construction, the soil was at the stage of desalinization and degradation of its earlier acquired solonetzic features. The exchangeable sodium percentage in it was less than 5%. It can be supposed that the stage of the soil salinization and alkalization took place earlier during the sharply arid phase of the Subboreal period (4.2–3.9 ka BP). The Srubnaya cultural epoch was characterized by milder and more humid climatic conditions. The morphological and chemical properties of this paleosol allow us to classify it as a residual-solonetzic typical chernozem.

The development of solonetzic features and salinization in this paleosol during the arid phase of the Subboreal period is quite explainable. Note that solonetzic chernozems are present in the modern soil cover of the studied region (the basin of the Severskii Donets and Sazhnovskii Donets rivers) on local slopes. This is caused by the presence of soluble salts in the parent material. In the arid epochs of the Holocene, the areas of solonetzic and slightly saline chernozems expanded. Their development was related to the transformation of the direction of the major geochemical fluxes in the landscape: the predominant downward (vertical) migration of substances in the humid epochs was replaced by the subhorizontal (lateral) migration of substances with some ascending movement of salts in the arid epochs. The presence of soluble salts and the high content of carbonates in the parent material on the interfluves specified the sensitivity of the local soils to the aridization of the climate.

CONCLUSIONS

The results of our study suggest that the evolution of chernozems in the center of the East European Plain can be characterized by the long-term (interglacial, full-Holocene) general trend and by short-term trends reflecting separate climatic stages of the Holocene.

The long-term trend in the evolution of ordinary chernozems developed from the loess-like calcareous loam consists of the continuous increase in the thickness of the humus horizons and the depth of the carbonate leaching (the depth of effervescence).

The short-term Late-Holocene trends of the natural evolution of chernozems are characterized by the spatial heterogeneity related to the latitudinal zonality (the forest-steppe and steppe zones) and the lithological composition of parent materials. In the Late Holocene, the changes in the thickness of the soil horizons were more pronounced in the leached and typical chernozems of the forest-steppe zone and less pronounced in the ordinary and southern chernozems of the steppe zone. Relatively shallow typical chernozems developed from thick calcareous loess-like loams have evolved into medium-deep and deep typical chernozems. In the case of a low content of carbonates in the parent material, the shallow typical chernozems have evolved into medium-deep leached chernozems. In the case of the presence of salt-bearing Paleogene and Neogene clayey sediments at a relatively shallow depth, the thin solonetzic typical chernozems have evolved into medium-deep and deep typical chernozems.

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