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ПРОБЛЕМЫ ПАЛЕОПОЧВОВЕДЕНИЯ И ГЕОАРХЕОЛОГИИ

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ПАЛЕОЧЕРНОЗЕМЫ ВРЕМЕНИ РАЗВИТИЯ СРУБНОЙ КУЛЬТУРЫ И ТРЕНДЫ ПОЗДНЕГОЛОЦЕНОВОЙ ЭВОЛЮЦИИ ПОЧВ ЛЕСОСТЕПИ ВОСТОЧНО-ЕВРОПЕЙСКОЙ РАВНИНЫ

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Выполнен сравнительный анализ признаков черноземов, погребенных под курганами периода срубной культурно-исторической общности (3600–3400 л. н.), их аналогов более ранних (4200–3700 л. н.) и более поздних (2500–2200 л. н.) периодов, а также современных компонентов почвенного покрова на территории центра Восточно-Европейской равнины. Черноземы периода срубной культуры формировались в обстановке заметных биоклиматических изменений, последовавших вслед за периодом среднесуббореальной аридизации климата. Установлено, что биохимическая перестройка профиля по содержанию почвенного органического вещества опережала морфологическую перестройку с формированием более мощной темноцветной части профиля черноземов. Автоморфные палеочерноземы срубного времени характеризовались большей однородностью морфологических свойств (на всех изученных участках – черноземы типичные) по сравнению с современными аналогами (возникли два ареала черноземов – выщелоченных и типичных). Черноземы выщелоченные возникли на участках с меньшими запасами карбонатов в почвообразующих породах по сравнению с чернозмами типичными. Общий тренд позднеголоценовой эволюции черноземов выщелоченных и типичных состоял в увеличении мощности гумусовых горизонтов (в среднем на 20 см) и почвенных профилей (в среднем на 20 см) при неизменности мощности переходной части профиля (A1B+BA1) и горизонтов B (Bк). Отличия состояли в разных глубинах выщелачивания почвенных профилей от карбонатов.

Ключевые слова: лесостепь, Восточная Европа, черноземы, эволюция почв, поздний голоцен, срубная культура

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1. INTRODUCTION

In Russian paleopedology, a large amount of information about features of the soils buried under kurgans of different historical periods has been accumulated during the last decades (Zolotun, 1974; Aleksandrovskiy, 1984; Gennadiev, 1984; Ivanov, 1992; Demkin, 1997; Chendev et al., 2010; Khokhlova et al., 2010; Puzanova et al., 2017; Prikhodko, 2018; etc.).

Interest in the soils of the mounds is primarily dictated by the possibility of a comparative analysis of the properties of the soils buried under the mounds and their modern (surface) analogues. This comparison of the soils is frequently used to reveal the differences in the environmental conditions between the time of burial (the moment of the mound construction) and the present time.

The presence of a large number of mounds as objects of cultural and historical heritage and as archives of the paleoenvironmental information on the territory of the European and Asian parts of Russia determined the specifics of the development of the soil-evolutionary direction in Russian soil science. One of the advantages of studying the soils buried under the mounds is their good preservation under the thick earthen constructions, which protect the paleosols from the influence of modern soil-forming processes.

In other regions of the world, the soils of kurgan constructions are studied much less frequently and often in a rather specific way – either by studying only soil formation on kurgan embankments (Ruhe, Schotles, 1956; Parsons et al., 1962), or by drilling kurgans and buried soils with the extraction of columns of soil material and analysis of a limited set of properties (Kristiansen et al., 2003; Molnar et al., 2004), and much less often – through a full-profile study of the buried soils (Hejcman et al., 2013).

Most of the soil-archaeological research carried out is based on the study of paleosols associated with the cultural layers of settlements of different periods, while the thickness of the sediments of ancient settlements overlying the paleosols is not always large enough to protect buried soils from diagenetic changes (Holliday, 2004; Gerlach et al., 2006; Vislouzelova et al., 2015; Kamnueva-Wendt et al., 2020; etc.), which can introduce errors in the research results.

Earlier studies of buried and surface soils were often limited to a comparative analysis of their properties within local areas (Aleksandrovskiy, 1984; Gennadiev, 1984; Ivanov, 1992). However, as the space of soil-archaeological research expanded and the key sites increased, prerequisites for reconstructing of the soil properties and the conditions of soil formation in a wider geographical space began to arise (Chendev, Ivanov, 2007; Chendev et al., 2015).

In the proposed article, the primary attention is focused on studying the soils buried under the mounds of the Srubnaya Cultural-Historical Community. The frequency of occurrence of these objects in modern landscapes is relatively high due to the wide distribution of the area of this culture in the middle of the 1st millennium BC on a large territory of the forest-steppe and steppe zones of the East European Plain – from the Urals to the Dnieper basin (Gorbunov, 1994). The high density of the burial mounds of this era was reflected in a large number of archaeological excavations, in which soil scientists also participated.

The purpose of this research is a comparative study of the features of chernozems buried under the mounds of the Srubnaya Cultural-Historical Community and chernozems of an earlier and later period in the centre of Eastern Europe.

2. OBJECTS AND METHODS OF RESEARCH

The territory of our study is the forest-steppe and steppe of the East European Plain, which includes the southern part of the Central Russian Upland and the adjacent areas of the Poltava and Oka-Don Plains. All studied objects are located between 49 and 52 degrees north latitude and 35–41 degrees east longitude (fig. 1).

A large number of objects (11 out of 16), were studied by the authors of the presented article in different years. Some objects for this research were taken from other works (Margolina et al., 1988; Akhtyrtsev, Akhtyrtsev, 1990; Ivanov, 1992).

The burial mounds studied at each site were usually single objects (except the *Belgorodsky*, *Bogdanovka*, *Bobrovsky*, *Graivoronsky* and *Gubkinsky* key sites) and consisted from single-layer, i.e. constructed in one go. The mounds were dated by an archaeological method (using artefacts) with an accuracy of the century. For the study region the chronology of the Srubnaya culture is not developed well and in detail. Therefore, a more accurate radiocarbon dating method for bone, coal and wood (from the central burials of the mounds) was also used. The range of construction dates for all the studied mounds is from 3360 to 3620 yr. BP (3510–3960 cal. yr. BP). This is consistent with the opinion of one of the well-known specialists in the studied archaeological culture I.F. Kovaleva, according to which the spread of the Srubnaya culture in the basin of the upper reaches of the Seversky Donetsk river was limited mainly to the interval of the 15th-14th (not calibrated) centuries BC (Kovaleva, 1990). In addition to the mounds of the Srubnaya archaeological culture, one mound (the *Gorki* key site) was built by representatives of the late Catacomb culture about 3600 yr. BP (3950 cal. yr. BP). This mound was included in the list of studied objects due to the same period of the Srubnaya culture's existence for assessing and analyzing paleosols. In most cases, the thickness of the studied constructions of mounds exceeded 1 meter. This height and loamy composition of the embankments ensure good preservation of the original features of paleosols (according to Demkin, 1997). The height of some of the studied mounds was less than 1 meter – 0.6–0.9 meters due to ploughing. Their height exceeded 1 meter until the 1950s. The decrease in the surface of the mounds due to steam-row crops introduction and the heavy agricultural machinery use occurred relatively recently. It did not affect of the initial features of soils buried under the mounds.

The parent materials are presented by loess loams and clays, and only in one area (the *Gorki* site) moraine loams and clays of the Moscow glaciation period were identified. The parent materials from west to east are changed from lighter to heavier granulometric composition. All the studied mounds were located on well-drained watersheds with deep groundwater. Chernozems are widespread in all studied areas (according to field research and (Natsional'nyi..., 2011). On the *Bobrovsky* site, the current groundwater depth was four or more meters under the surface meadow-chernozemic soils, typical for the of the Oka-Don Plain's interfluves (Akhtyrtsev, Akhtyrtsev, 1990).

Most of the studied sites (14) are located in the forest-steppe area, and only two sites (*Bogdanovka* and *Starokriushinsky*) are located to the south, in the steppe zone (fig. 1).

All have studied buried soils had natural undisturbed surfaces, what was detected according to their flat or slightly wavy boundary with mound material; in most cases, on the surface of buried soils has been a visible thin pale yellow layer of parent material – ejection of loam from the grave pit of the central burials. By this layer border between the mound and buried soil was detected quite correctly.

The main approach of the study is the method of soil chrono-sequences, which is based on a comparative analysis of dated soils (buried and newly formed in mounds) and their surface full-Holocene analogues,

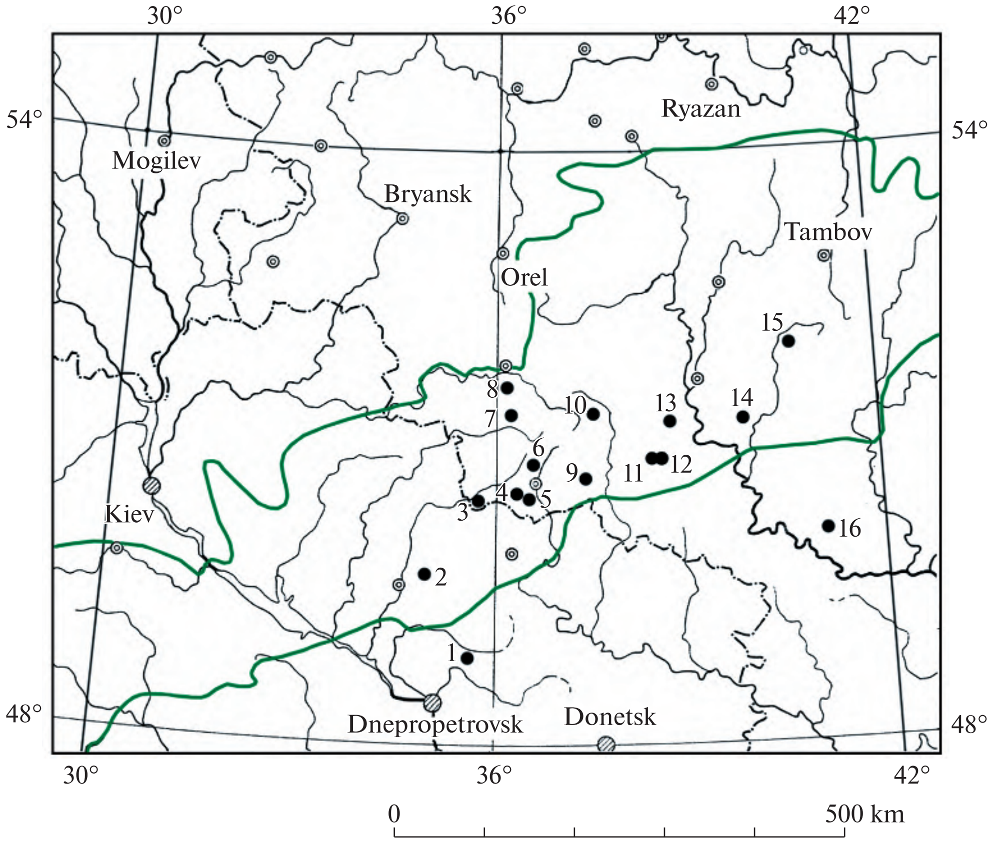

Fig. 1. Location of sites for soil-archaeological research of the Bronze Age burial mounds, created 3400–3600 years ago.

Site names: 1 – Bogdanovka (Ivanov, 1992); 2 – Storozhevoye (Chendev et al., 2011); 3 – Grayvoronsky (Chendev et al., 2015); 4 – Staraya Nelidovka (unpublished data); 5 – Belgorodsky (Chendev et al., 2015); 6 – Prokhorovsky (Chendev, 2008); 7 – Drozdy (Aleksandrovskiy, 1983; Margolina et al., 1988); 8 – Dubroshina (Aleksandrovskiy, 1983; Margolina et al., 1988); 9 – Gorozhenoe (unpublished data); 10 – Gubkinsky (Chendev, 2008); 11 – Novoe Ukolovo (unpublished data); 12 – Gorki (unpublished data); 13 – Boldyrevka (unpublished data); 14 – Bobrovsky (Akhtyrtsev, Akhtyrtsev, 1990); 15 – Chamlyk-Nikolsky (unpublished data); 16 – Starokriushinsky (Margolina et al., 1988). Green lines mark the northern and southern boundaries of the forest-steppe area.

Рис. 1. Схема местоположения участков почвенно-археологических исследований курганов бронзового века, созданных в интервале времени 3400–3600 лет назад.

Названия участков: 1 – Богдановка (Иванов, 1992); 2 – Сторожевое (Чендев и др., 2011); 3 – Грайворонский (Чендев и др., 2015); 4 – Старая Нелидовка (неопубликованные данные); 5 – Белгородский (Чендев и др., 2015); 6 – Прохоровский (Чендев, 2008); 7 – Дрозды (Александровский, 1983; Марголина и др., 1988); 8 – Дуброшина (Александровский, 1983; Марголина и др., 1985); 9 – Гороженое (неопубликованные данные); 10 – Губкинский (Чендев, 2008); 11 – Новое Уколово (неопубликованные данные); 12 – Горки (неопубликованные данные); 13 – Болдыревка (неопубликованные данные); 14 – Бобровский (Ахтырцев, Ахтырцев, 1990); 15 – Чамлык-Никольский (неопубликованные данные); 16 – Старокриушинский (Марголина и др., 1988). Зеленые линии – северная и южная границы лесостепи.

formed near archaeological sites in similar lithological and geomorphological positions (fig. 2).

Based on the differences between the buried and surface soils, conclusions were drawn about the changes in climatic conditions that took place.

In turn, the method of soil chrono-sequences includes a fundamental method of field soil research – the method of morphological description of the soil profile. The results of the morphological description of the studied soils have been presented in an abbreviated form in this article – the characteristics of the thickness of the soil horizons and the depth of effervescence for buried and surface soils are given in the text and tables.

For some key sites, laboratory analyses of soils, including characteristics such as bulk density (samples were taken using a cutting rings), particle size distribution (GOST (State Standard) 12536), pH aqueous GOST 26423–85), total organic carbon (according to Tyurin's (wet combustion) method (GOST 26213–91), the content of CO_2 carbonates by the acidimetric method were provided. These types of analysis of soil samples were carried out in the laboratories of the National Research University "Belgorod State University" and the Federal State Budgetary Institution "Center of Agrochemical Service "Belgorodsky"". Statistical calculations of the studied indicators (arithmetic mean, error of the mean, standard deviation, coefficient

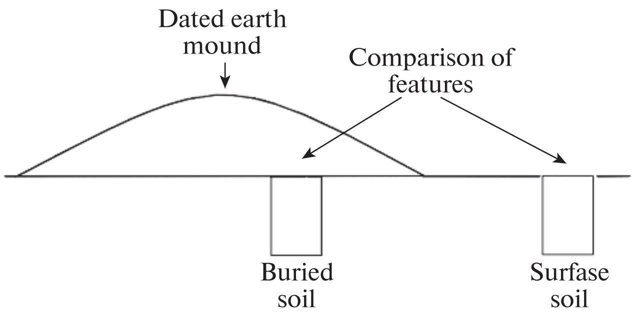

Fig. 2. Illustration of the method of soil chrono-sequences used in our soil-archaeological studies.

Рис. 2. Иллюстрация метода почвенных хронорядов в проведенных авторами почвенно-археологических исследованиях.

of variation) were performed using the STATISTICS program in Excel.

Two samples (bone from a mound at the *Staraya Nelidovka* site and a wood from a burial at the *Boldyrevka* site) were dated in the Isotope Research Laboratory of the Center for Collective Use "Geo-ecology" of the Russian State Pedagogical University A.I. Herzen.

The radiocarbon dating of the samples at *Gorozhenoe* site was carried out in the radiocarbon laboratory of the Institute of Environmental Geochemistry of the National Academy of Sciences of Ukraine (Kiev, Ukraine) using the liquid scintillate method (LSC) (Skripkin, Kovalyukh, 1998). The ^{14}C isotope content was measured on a Quantulys1220 T low-background spectrometer. The calibration of radiocarbon dates was carried out by A.V. Dolgikh (Institute of Geography RAS) using the OxCal v4.2.4 program (Bronk, Lee, 2017) based on the IntCal 13 calibration curve (Reimer et al., 2013).

3. RESULTS AND DISCUSSION

Srubnaya culture appeared in a wide geographic space between the Dnieper in the west and the Urals in the east. The standard burial ritual by representatives of this culture was burial in pits surrounded by wooden structures – log constructions, which were closed from above with wooden chopping blocks and covered with the ground until the formation of hills – mounds with different diameters and heights. According to Gorbunov (1994), the emergence of the Srubnaya culture in Eastern Europe is a unique phenomenon that marks the formation of the same type of rituals and similar infrastructure over a large territory. The reason for the spread of representatives of the Srubnaya cultural and historical community could be favourable climatic changes – the mid-Subboreal climatic optimum, which made it possible to widely develop landscapes and use cattle breeding by tribes of this culture in the forest-steppe and steppe of the East European Plain.

According to palynological data, the second half of the Subboreal period of Holocene (between 3970 and 3550 yr. BP) was marked by warming and humidification of the climate in the study area, which, in particular, led to an increase in the expansion of forests on the steppe areas (Spiridonova, 1991; Serebryannaya, 1992; Shumilovskikh et al., 2018). The found wood in the burials also testifies to the significant forest cover of the territory. Comparative analysis of the buried soils formed in different intervals of the second half of the Holocene in the typical chernozems modern area (forest-steppe zone), conveys a clearly defined regularity of the growth of the thickness of humus horizons and, in general, of the humified part of the profiles (A1 + A1B + BA1 horizons) of chernozems. Moreover, the process of leaching carbonates is also traced in studied buried soils (tabl. 1).

Table 1. Changes in the morphological features of typical chernozems in the centre of the forest-steppe zone of the East European Plain over the past 4200 years (uncalibrated)

Таблица 1. Изменение морфологических свойств черноземов типичных центра лесостепной зоны Восточно-Европейской равнины за последние 4200 лет (некалиброванных)

Soil feature, % of modern features	Chronointervals (yr. BP) and the number of mounds studied (*n*)		
	4200–3700, *n* = 5	3600–3400, *n* = 9	2600–2200, *n* = 16
The thicknessof the A1 horizon	57.0 ± 4.6	69.3 ± 6.2	95.6 ± 6.4
The thickness of Ah + AhB + BAh horizons	73.9 ± 2.3	80.0 ± 1.0	99.2 ± 4.0
Depth of effervescence	24.8 ± 13.2	57.1 ± 3.4	53.1 ± 4.5

Note: data for chronointervals are used: 4200–3700 yr. BP – unpublished data of the authors – two objects in the Poltava oblast, (Chendev, 2008) – one object in the Belgorod oblast, (Akhtyrtsev, Akhtyrtsev, 1994) – two objects in the Voronezh oblast; 3600–3400 yr. BP – unpublished data of the authors – three objects in Poltava, Belgorod and Voronezh oblasts, (Chendev, 2008) – four objects in the Belgorod oblast (Aleksandrovskiy, 1983; Margolina et al., 1988) – two objects in the Kursk oblast; 2600–2200 y. a. – unpublished data of the authors – one object in the Voronezh oblast, (Chendev, 2008) – 15 objects in the Belgorod and Voronezh oblasts.

Примечание: использованы данные для хроноинтервалов: 4200–3700 л. н. – неопубликованные данные авторов (два объекта в Полтавской области), Ю.Г. Чендева (2008) один объект в Белгородской области), Б.П. Ахтырцева, А.Б. Ахтырцева (1994) (два объекта в Воронежской области); 3600–3400 л. н. – неопубликованные данные авторов (три объекта в Полтавской, Белгородской и Воронежской областях), Ю.Г. Чендева (2008) (четыре объекта в Белгородской области), А.Л. Александровского (Александровский, 1983; Марголина и др., 1988) (два объекта в Курской области); 2600–2200 л. н. – неопубликованные данные авторов (один объект в Воронежской области), Ю.Г. Чендева (2008) (15 объектов в Белгородской и Воронежской областях).

The results of studying the morphometric characteristics of paleochernozems of the Srubnaya culture, their modern analogues in the forest-steppe part of the study area, and the differences revealed between them are reflected in tabl. 2. Table 2 is structured following the surface soils to different genetic groups: firstly, areas are indicated where the surface soils are leached chernozems, then areas with typical chernozems, and at the end, one area with meadow-chernozem soils is located.

According to the results of statistical calculations, in the studied paleosoil space within the automorphic positions of the relief (the *Bobrovsky* site was excluded), the thickness of the humified part of the soil profiles (A1 + A1B + BA1) as well as the total thickness of the soil profiles were characterized by minimal variability, and the maximum variability has been detected for the depth of effervescence (tabl. 3).

When comparing the average values of morphometric features of surface and paleochernozems, significant statistical differences are determined by such characteristics as the thickness of the humus horizons, the humified part of the profiles and the depth of effervescence. The high variability of all indicators (the coefficients of variation are in the range of 24–74%, tabl. 3) indicates the intraregional differences in the development of soil formation in the studied space, both in the past and at present. Table 3 shows an increase of the entire soil profiles up to 21 cm during the Late Holocene, which is comparable to an increase in the thickness of A1 horizons up to 20 cm.

At the same time, the thickness of the lower humus part of the profile (A1B + BA1, 23–27 cm), B (32 cm) and BC horizons (30–31 cm) remained unchanged.

Thus, over the past 3500 years, the leading role in the evolution of the profiles of chernozems on the territory of the forest-steppe zone in the centre of the East European Plain was played by the thickness of humus horizons and the depth of carbonates occurrence.

A comparative analysis of the temporal development of individual units of soil classification, – subtypes of leached chernozems ($n = 6$) and typical medium-thick chernozems ($n = 7$) is reflected in tabl. 4 (areas with thick and super-thick chernozems, in accordance with the traditional Russian soil classification (Classificatsiya..., 1977) (*Dubroshina* and *Drozdy* sites (Aleksandrovskiy, 1983; Margolina et al., 1988)) are excluded). Chernozems buried 3600–3400 yr. BP in the modern distribution areas of the two indicated subtypes of chernozems belongs to one unit of typical thin (close to medium thick) chernozems (tabl. 4). Throughout the studied area, they are characterised by the identity of the depths of the carbonate table (24–26 cm). However, in the area of distribution of modern typical chernozems, the development of more thick soil profiles took place in comparison with paleochernozems in the area of modern leached chernozems distribution (tabl. 4).

In the modern soil space, contrasting differences between the surface leached and typical chernozems are achieved only by significant differences in the depth of carbonate occurrence (in leached chernozems – on average 111 cm, and in typical chernozems – 56 cm) and weak insignificant differences in the thickness of all soil horizons and soil profiles in the whole. The considered surface subtypes of chernozems at the generic level belong to the category of medium-thick ones, with the thickness of the humified part of the profiles 73–76 cm (tabl. 4).

A comparative analysis of modern and buried soils revealed the formation of one typical chernozem area in the Srubny period within the two modern areas presented by leached and typical chernozems (tabl. 4). However, there were spatial differences within this area in the Srubny period – in place of modern leached chernozems soil profiles and horizons had less thickness comparatively with paleosoils within the modern typical chernozem area (tabl. 4). In particular, the less developed humified part of profiles ([A1+A1B+BA1]) in the paleospace of modern leached chernozems (tabl. 4) can be an indicator of less soil fertility in these places in the Srubny period.

We assume that one of the most probable reasons for the less or more degree of development chernozems within palaeosoil space could be the difference in the combination of soil-forming factors in the compared areas throughout a significant part of the Holocene. Among these differences, the most probable were intraregional differentiation of climatic conditions, as well as local differences in the lithological composition of parent materials. Leached chernozems tend to be form on more clayey and less calcareous soil-forming rocks in comparison with the rocks on which typical chernozems were formed. Previously, we have already expressed that the leached chernozems were formed in areas where loess loams were characterized by an initially smaller amount of carbonates (Chendev, 2008). Research carried out at new sites in our article confirms this assumption. As an example, we provided a comparison of the profile distribution of carbonates and their reserves in a 2-meter stratum of automorphic buried and surface leached chernozems in the *Staraya Nelidovka* site (Belgorod oblast), and buried and surface typical chernozems in *Boldyrevka* site (Voronezh oblast) (tabl. 5, fig. 3).

The general pattern of the two study areas is the leaching of carbonates from the upper one-meter layer of chernozems and their accumulation in the lower part of the profiles, in the 100–200 cm layer during the Late Holocene. The differences lie in the lower content and pools of carbonates in the buried and surface soils of the *Staraya Nelidovka* site concerning the buried and surface soils of the *Boldyrevka* site (tabl. 5, fig. 3).

Table 2. Morphometric features of the buried soils of the Srubnaya culture and their modern surface analogues on the territory of the forest-steppe centre of the East European Plain (compiled from unpublished data of the authors (sites *Boldyrevka*, *Gorozhenoe*, *Gorki*, *Novoye Ukolovo*, *Staraya Nelidovka*, *Storozhevoe*, *Chamlyk-Nikolsky*) and data from papers (Aleksandrovskiy, 1983; Margolina et al., 1988; Akhtyrtsev, Akhtyrtsev, 1990; Chendev, 2008)

Таблица 2. Морфометрические признаки подкурганных почв срубного времени и их фоновых аналогов на территории лесостепи центра Восточно-Европейской равнины (составлено по неопубликованным данным авторов (участки *Болдыревка, Гороженое, Горки, Новое Уколово, Старая Нелидовка, Сторожевое, Чамлык-Никольский*) и данным из работ (Aleksandrovskiy, 1983; Margolina et al., 1988; Akhtyrtsev, Akhtyrtsev, 1990; Chendev, 2008)

No	Soil	Thickness (for effervescence – depth), numerator – cm, denominator –% of modern values					
		A1	A1B + BA1	A1 + A1B + BA1	B	Profile	Effervescence
Staraya Nelidovka site, 3620 ± 45 yr. BP (radiocarbon date), surface soil – leached chernozem							
1	buried	18/42.9	13/59.1/	31/48.4	39/95.1	111/80.4	32/27.1
	surface	42/100	22/100	64/100	41/100	138/100	118/100
	difference	+24/+51.1	+9/+ 40.9	+ 33/+ 51.6	+2/+4.9	+27 /+18.6	+86 /+72.9
Belgorodsky-1 site, 3500 yr. BP (arch. date), surface soil – leached chernozem							
2	buried	46/97.9	22/71	68 /87.2	21/84	113/78.5	24/16.7
	surface	47/100	31/100	78/100	25/100	144/100	144/100
	difference	+1/+ 2.1	+9/+29	+10/+ 12.8	+4/+16	+31 /+21.5	+120/+83.3
Prokhorovsky site, 3500 yr. BP (arch. date), surface soil – leached chernozem							
3	buried	35/56.5	22/122.2	57/71.3	21/95.5	103/81.7	35/37.2
	surface	62/100	18/100	80/100	22/100	126/100	94/100
	difference	+27/+43.5	–4/–22.2	+23/+28.7	+1/+4.5	+23 /+18.3	+59/+62.8
Gorozhenoe site, 3360 ± 25 yr. BP (radiocarbon date), surface soil – leached chernozem							
4	buried	17/41.5	15/65.2	32/50	20/80	114/100	17/23.6
	surface	41/100	23/100	64/100	25/100	114/100	72/100
	difference	+24/+58.5	+8/+34.8	+32/+50.0	+5/+20	0/0	+55 /+76.4
Novoe Ukolovo site, 3500 yr. BP (arch. date), surface soil – leached chernozem							
5	buried	35/67.3	10/55.6	45/64.3	21/48.8	113/80.1	20/22.7
	surface	52/100	18/100	70/100	43/100	141/100	88/100
	difference	+17/+32.7	+8/+44.4	+25/+35.7	+22/+51.2	+28 /+19.9	+68/+77.3
Chamlyk-Nikolsky site, 3600-3550 yr. BP (arch. date), surface soil – leached chernozem							
6	buried	36/38.2	24/171.4	50/61	25 /69.4	98/71	14/9.3
	surface	68/100	14/100	82/100	36/100	138/100	150/100
	difference	+42/+61.8	–10/–71.4	+32/+39	+11/+30.6	+40/+29	+136/+90.7
Storozhevoye site, 3500 yr. BP (arch. date), surface soil – typical chernozem							
7	buried	17/48.6	38/115.2	55/80.9	47/97.9	144/90	17/25
	surface	35/100	33/100	68/100	48/100	160/100	68/100
	difference	+18/51.4	–5/–15.2	+13/+19.1	+1/+2.1	+16 /+10	+51/+75
Grayvoronsky site, 3500 yr. BP (arch. date), surface soil – typical chernozem							
8	buried	52/80	30/85.7	82/82	40/160	145/93.5	25 /59.5
	surface	65/100	35/100	100/100	25/100	155/100	42 /100
	difference	+13/+20	+5/+14.3	+18/+18	–15/–60	+10/+6.5	+17/+40.5
Belgorodsky -2 site, 3500 yr. BP (arch. date), surface soil – typical chernozem							
9	buried	50/74.6	16/76.2	66/75	19/73.1	107/79.3	25/55.6
	surface	67/100	21/100	88/100	26/100	135/100	45/100
	difference	+17 /+25.4	+5/+23.8	+22 /+25	+7/+26.9	+28 /+20.7	+20/+44.4

Table 2. Продолжение

No	Soil	Thickness (for effervescence – depth), numerator – cm, denominator –% of modern values					
		A1	A1B + BA1	A1 + A1B + BA1	B	Profile	Effervescence
		Dubroshina site, 3500 yr. BP (arch. date), surface soil – typical chernozem					
10	buried	65/72.2	50/76.9	115/74.2	45/112.5	220/86.3	80/71.4
	surface	90/100	65/100	155/100	40/100	255/100	112/100
	difference	+25/+27.8	+15/+23.1	+40/+25.8	–5/–12.5	+35 /+13.7	+32/+28.6
		Drozdy site, 3500 yr. BP (arch. date), surface soil – typical chernozem					
11	buried	55/78.6	45/75	100/76.9	–	–	100/80
	surface	70/100	60/100	130/100	–	–	125/100
	difference	+15/+21.4	+15/+25	+30/+23.1	–	–	+25/+20
		Gubkinsky-1 site, 3500 yr. BP (arch. date), surface soil – typical chernozem					
12	buried	30/54.5	25/250	55/84.6	20/90.9	100/82	25/41.7
	surface	55/100	10/100	65/100	22/100	122/100	60/100
	difference	+25/+45.5	–15/–150	+10/+15.4	+2/+ 9.1	+22/+18	+35 /+58.3
		Gubkinsky-2 site, 3500 yr. BP (arch. date), surface soil – typical chernozem					
13	buried	37/56.9	30/120	67/74.4	40/200	130/100	30/42.9
	surface	65/100	25/100	90/100	20/100	130/100	70/100
	difference	+28/+43.1	–5/–20	+23/+25.6	–20/–100	0/0	+40/+57.1
		Gorki site, 3600 yr. BP (arch. date), surface soil – typical chernozem					
14	buried	32/106.7	17/89.5	49/100	61/135.6	–	50/119
	surface	30/100	19/100	49/100	45/100	–	42/100
	difference	–2/–6.7	+2/+10.5	0/0	–16/–35.6	–	–8/–19
		Boldyrevka site, 3383 ± 45 yr. BP (radiocarbon date), surface soil – typical chernozem					
15	buried	24/52.2	27/108	51/71.8	31/114.8	127/92.7	12/18.5
	surface	46/100	25/100	71/100	27/100	137/100	65/100
	difference	+22/47.8	–2/–8	+20/+28.2	–4/–14.8	+10/+7.3	+53/+71.5
		Bobrovsky site, 3500 yr. BP (arch. date), surface soil – meadow-chernozem soil					
16	buried	36/75	36/73.5	72/74.2	60/–	142/–	0/0
	surface	48/100	49/100	97/100	–	–	54/100
	difference	+ 12/+25	+13/+26.5	+25/+25.8	–	–	+54/+100

Note: in table "–" – no data.

Примечание: в таблице обозначение "–" – отсутствие данных.

In the two-meter soil layer of the compared sites, the carbonate stocks in the surface soils differ by 1.7 times and the buried soils by 2.9 times, towards higher values in the area of typical chernozems (tabl. 5). The given example shows the initial spatial differences in content and pools of carbonates of the parent materials, which influenced the Late Holocene evolution of the soils and soil cover. The natural spatial variability of carbonates distribution in the parent materials dictates the mosaic distribution of the areas of leached and typical chernozems.

A comparative analysis of the distribution of the Corg content through the profile in the buried and surface chernozems is of particular interest. As is known, after burial, diagenetic changes in some features occur in soils, including the content and stocks of organic matter (Ivanov, 1992; Demkin, 1997). The decrease in organic matter content is associated with the process of its mineralization by microorganisms, which occurs especially intensively in the uppermost layers of buried soils (Zolotun, 1974; Ivanov, 1992). That is why the carbon content of organic matter in buried chernozems is lower than in the surface soils in most cases. It is believed that over 250–300 years after the burial, about 50% of the original humus stocks are lost in the upper layers of chernozems. Further, the intensity of mineralization of organic matter weakens, but continues for many millennia. So, in the upper

Table 3. Average morphometric characteristics of chernozems buried 3600–3400 yr. BP, and their surface analogues in automorphic landscapes of the forest-steppe zone in the centre of the East European Plain
Таблица 3. Средние морфометрические признаки подкурганных черноземов, погребенных 3600–3400 л. н., и их фоновых аналогов в автоморфных ландшафтах лесостепи центра Восточно-Европейской равнины

Statistical indicator	Thickness, cm					
	A1	A1B+BA1	A1+A1B+BA1	B	profile	Depth of effervescence
Buried chernozems, n = 15						
$X \pm \delta_X$	36 ± 3.8	26 ± 3.0	62 ± 5.9	32 ± 3.5	125 ± 9.0	34 ± 6.5
δ	14.88	11.57	23.04	13.25	32.38	25.00
V, %	41	44	37	41	26	74
Surface chernozems, n = 15						
$X \pm \delta_X$	56 ± 4.1	28 ± 4.0	84 ± 7.1	32 ± 2.6	146 ± 9.7	86 ± 9.3
δ	15.92	15.60	27.42	9.84	35.09	36.05
V, %	28	56	33	31	24	42

Table 4. Morphometric features of the buried chernozems 3600–3400 yr. BP and their surface analogues in the distribution areas of leached and typical automorphic chernozems on the territory of the forest-steppe centre of the East European Plain
Таблица 4. Морфометрические признаки подкурганных черноземов, погребенных 3600–3400 л. н., и их фоновых аналогов в ареалах распространения автоморфных черноземов выщелоченных и типичных на территории лесостепи центра Восточно-Европейской равнины

Modern soil area	Statistical indicator	Thickness, cm					Depth of effervescence, cm
		A1	A1B+BA1	A1+A1B+BA1	B	profile	
	Buried chernozems, n = 6						
Leached chernozems	$X \pm \delta_X$	30 ± 4.6	18 ± 2.3	48 ± 5.9	25 ± 3.0	109 ± 2.7	24 ± 3.4
	δ	11.26	5.75	14.39	7.31	6.59	8.36
	V, %	37	32	30	29	6	35
	Surface chernozems, n = 6						
	$X \pm \delta_X$	52 ± 4.5	21 ± 2.4	73 ± 3.3	32 ± 3.7	134 ± 4.6	111 ± 12.9
	δ	10.97	5.87	8.07	9.12	11.34	31.62
	V, %	21	28	11	29	8	28
	Buried chernozems, n = 7						
Typical chernozems	$X \pm \delta_X$	35 ± 4.9	26 ± 2.9	61 ± 4.4	37 ± 5.7	126 ± 7.6	26 ± 4.6
	δ	12.88	7.73	11.67	15.00	18.64	12.05
	V, %	37	30	19	41	15	46
	Surface chernozems, n = 7						
	$X \pm \delta_X$	52 ± 5.7	24 ± 3.2	76 ± 6.6	30 ± 4.3	140 ± 6.0	56 ± 4.8
	δ	15.17	8.50	17.58	11.27	14.72	12.58
	V, %	29	35	23	38	11	22

part of the buried chernozems of the Early Iron Age, about 40% of the original stocks of humus remain, and in the paleochernozems of the Bronze – Eneolithic Ages – about 30% of the original stocks (Zolotun, 1974; Ivanov, 1992; Demkin, 1997). Our calculations show that these are only general assumptions that require clarification.

Table 6 and fig. 4 show the data of the layered distribution of the organic matter content in the buried chernozems of the centre of the East European Plain within three different historical periods, expressed as a percentage relative to the values in identical layers of modern (surface) chernozems. In each chrono-sequence, averaged characteristics of paired compari-

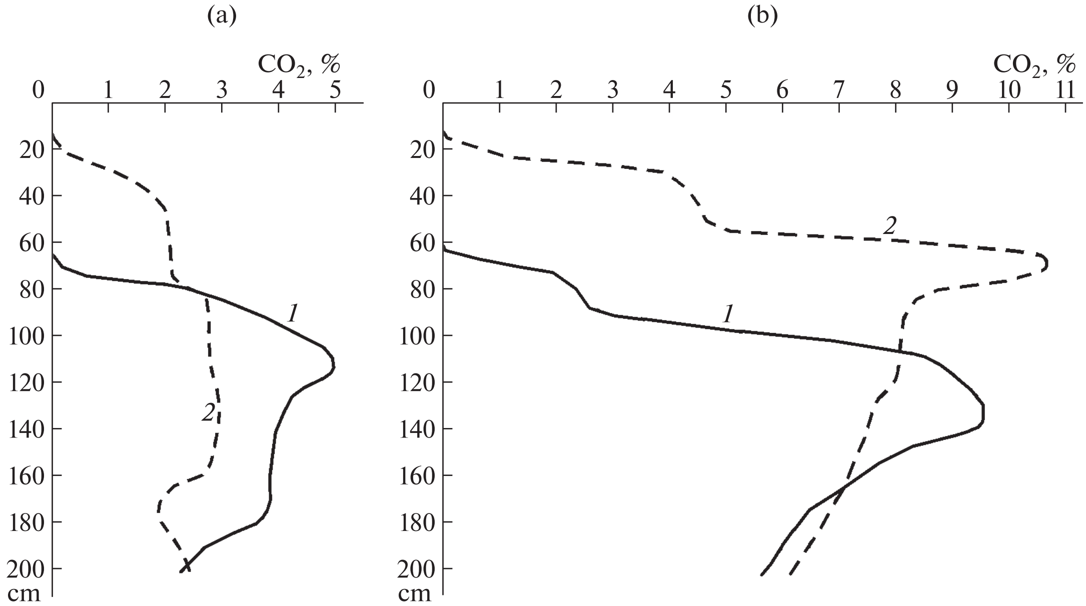

Fig. 3. Profile distributions of the carbonate CO_2 content in the soils of the Staraya Nelidovka ((a), surface soils – leached chernozems) and Boldyrevka sites ((b), surface soils – typical chernozems). *1* – the distribution of the carbonate CO_2 in the surface soils, *2* – the distribution of the carbonate CO_2 in the soils buried under the mounds of the Srubnaya culture period.

Рис. 3. Профильные распределения содержания CO_2 карбонатов в почвах участков Старая Нелидовка ((a), фоновые почвы – черноземы выщелоченные) и *Болдыревка* ((b), фоновые почвы – черноземы типичные). *1* – распределение показателя в фоновых почвах, *2* – распределение показателя в погребенных под курганами срубного времени почвах.

sons of buried and surface chernozems are presented by several sites (from 4 to 6).

As can be seen from the data in tabl. 6 and fig. 4, the paleochernozems of the Srubnaya culture (3600–3400 yr. BP) contain equal or greater content of organic matter in comparison with the paleochernozems buried about 1 thousand years later – in the Scythian period of the Early Iron Age.

We can conclude that during the period of the Srubny culture's existence, the climatic conditions in the forest-steppe area were very favorable for the formation of the humus-rich fertile chernozems. Probably, first of all, there was form hidden (bio-chemical, still without visual properties) enrichment of organic matter, and then (to the end of the Subboreal period, yet after the Srybny epoch), – its manifestation in morphological properties (thickness of A1 horizon and its dark color) (tabl. 1, fig. 4).

Table 5. Carbonates carbon stocks, t/ha in soil profiles of *Staraya Nelidovka* and *Boldyrevka* sites
Таблица 5. Запасы $C_{карб}$, т/га в профилях почв участков Старая Нелидовка и Болдыревка

Soil	The layer, cm		
	0–100	100–200	0–200
Staraya Nelidovka site			
Surface	40.12	171.66	211.78
Buried	68.31	110.11	178.42
Difference	–28.19	+61.55	+33.36
Boldyrevka site			
Surface	36.18	330.88	367.06
Buried	216.75	294.26	511.01
Difference	–180.57	+36.62	–143.95

Table 6. Organic carbon content by layers in buried automorphic chernozems of different periods, % of modern values (forest-steppe centre of the East European Plain, modern typical chernozems area)
Таблица 6. Послойное содержание органического углерода в подкурганных автоморфных черноземах разных периодов, % от современных значений (Центральная лесостепь, фоновый компонент почвенного покрова – черноземы типичные)

Layer, cm	Time of the burial, yr. BP, *n* – number of objects		
	4200–3700, *n* = 5	3600–3400, *n* = 6	2500–2200, *n* = 4
0–20	47 ± 3	70 ± 3	68 ± 5
20–40	45 ± 4	65 ± 4	71 ± 9
40–60	46 ± 7	80 ± 7	76 ± 12
60–80	43 ± 9	73 ± 17	86 ± 10
80–100	54 ± 12	91 ± 23	82 ± 11
100–120	65 ± 9	109 ± 21	80 ± 13
120–140	75 ± 9	95 ± 16	95 ± 8
140–160	89 ± 17	104 ± 21	93 ± 10

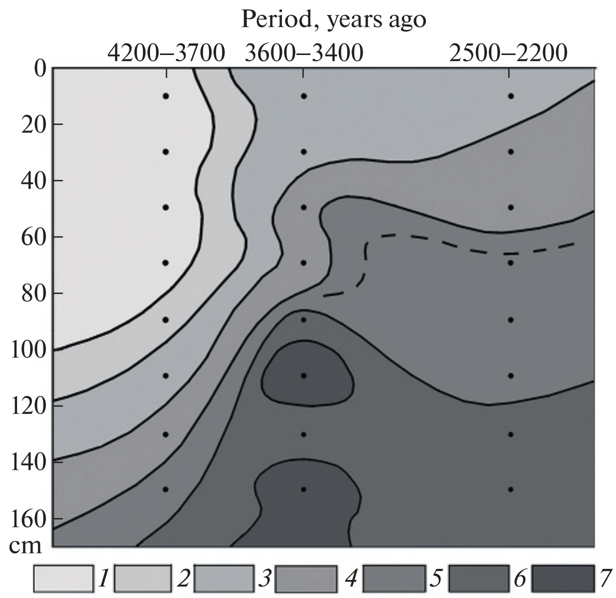

Fig. 4. Distribution of the organic carbon content in the profiles of buried chernozems of different periods (in % of modern values) within the modern typical chernozems area. *Organic carbon content from the current level, in %: 1* – less than 50, *2*–50–60, *3*–60–70, *4*–70–80, *5*–80–90, *6*–90–100, *7* – more than 100.

Рис. 4. Распределение содержания органического углерода в профилях подкурганных черноземов разных периодов (в % от современных значений) на территории распространения современных черноземов типичных. Содержание органического углерода от современного уровня, %: *1* – <50, *2*–50–60, *3*–60–70, *4*–70–80, *5*–80–90, *6*–90–100, *7* – >100.

In fig. 5 are represented distribution areas of the thicknesses of the humified part of the chernozems buried in the Srubny period (fig. 5, (a)), and also isohumus bands (fig. 5, (b)) are reflected the spatial differences of the buried chernozems of the Srubny period on soil organic matter content in the 0–20 cm layer.

According to the given schematic maps, the territory of the Central forest-steppe and adjacent steppe territories during the Srubny period was heterogeneous in terms of thickness of the humified part of soil profiles and organic matter content. Areas with the thickest humified part of the profiles of chernozems (fig. 5, (a)), are probably, related to optimal moisture regime (it was previously hypothetically associated with the close location of the Voeykov axis (Chendev et al., 2015). It was also noted that the organic matter content in the soils in the Srubny period increased eastward (fig. 5, (b)). This pattern for the surface soil cover of the East European chernozems at the end of the XIX century was established by Dokuchaev (Dokuchaev, 1883).

4. CONCLUSIONS

The conducted research allows us to draw a number of the following most important conclusions.

1. The Srubny period was marked by a change in natural conditions that followed the arid climate episode in the Middle Subboreal time on the East European Plain. The humus-rich part of the profile of the meadow-steppe chernozems of the forest-steppe zone

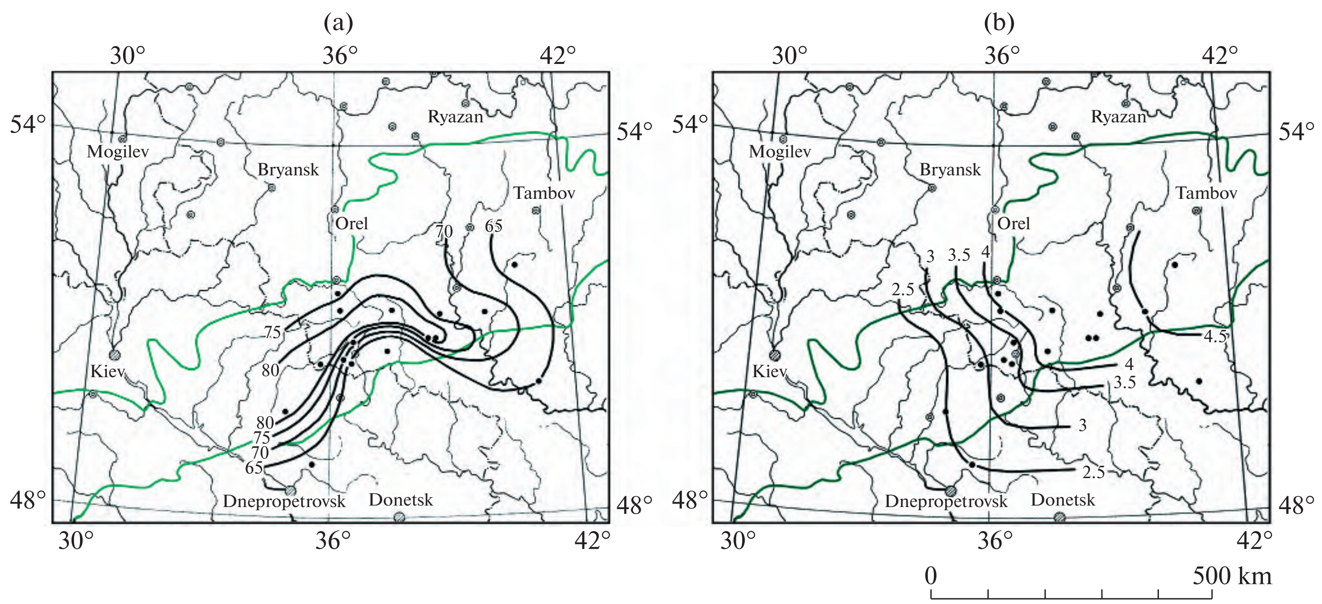

Fig. 5. The thickness of the humus-rich part of the profiles of the buried chernozems in the Srubny period (% of the current values) (a) and the humus content in the 0–20 cm layer of these soils, abs. % (b). Compiled on unpublished and literature data (noted in fig. 1).

Рис. 5. Мощность гумусированной части профилей подкурганных черноземов срубного времени (% от современных значений) (a) и содержание гумуса в слое 0–20 см этих почв, абс. % (b). Составлено по неопубликованным данным авторов статьи и литературным сведениям (указанным в подписи к рис. 1).

began to grow, and a less expressive tendency for leaching of carbonates was noted. "Hidden" (biochemical) enrichment of organic matter took place earlier than its manifestation in morphological properties of chernozems (growth of A1 horizon and its dark color formation). Buried chernozems of the Srubnaya culture in comparison with their later analogues of the Early Iron Age contain more organic matter despite the longer time of diagenesis.

2. On the territory of the forest-steppe centre of Eastern Europe, the automorphic paleochernozems of the Srubny period were characterised by a greater homogeneity of morphological properties (in all studied areas, they were identified as typical chernozems with high carbonate table) compared to their modern analogues (two areas of chernozems were formed – leached and typical). Leached chernozems are located in areas with lower carbonate content in the parent materials compared to the areas of typical chernozems.

3. The general trend of the Late Holocene evolution of leached and typical automorphic chernozems consisted of an increase in the thickness of humus horizons (by an average of 20 cm) and soil profiles (by an average of 20 cm). In contrast, the thickness of the transitional part of the profile (A1B + BA1) and horizons B (Bk) remained the same. Differences were connected with different depth of leaching from carbonates in the studied soils.

PALEOCHERNOZEMS OF THE SRUBNAYA CULTURE PERIOD AND TRENDS OF LATE HOLOCENE EVOLUTION OF SOILS IN THE EAST-EUROPEAN PLAIN FOREST-STEPPE

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A comparative analysis of the features of the chernozems buried under the mounds of the Srubnaya culture (3600–3400 years ago), earlier (4200–3700 years ago) and later analogues (2500–2200 years ago) have been carried out. Also, modern chernozems of the East European Plain central part were studied. The chernozems of the Srubnaya culture period were formed in an environment of noticeable bioclimatic transformations after the period of the Middle Subboreal climate aridization. It was found that the biochemical rearrangement of the profile in terms of the content of soil organic matter outplaced the morphological transformation with the formation of a thicker dark-colored part of the chernozem profile. The automorphic paleochernozems of the Srubny period were characterised by a greater homogeneity of morphological properties (in all studied areas, they were identified as typical chernozems with high carbonate table) compared to their modern analogues (two areas of chernozems were formed – leached and typical). Leached chernozems were formed in areas with lower carbonate content in the parent materials compared to the areas of typical chernozems. The general trend of the Late Holocene evolution of leached and typical automorphic chernozems consisted of an increase in the thickness of humus horizons (by an average of 20 cm) and soil profiles (by an average of 20 cm). In contrast, the thickness of the transitional part of the profile (A1B + BA1) and horizons B (Bk) remained the same. Differences were connected with different depth of leaching from carbonates in the studied soils.

Keywords: forest-steppe, Eastern Europe, chernozems, soil evolution, Late Holocene, Srubnaya culture

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