

GENESIS AND GEOGRAPHY OF SOILS

Short-Range Lateral Variation of Humus and Carbonate Profiles of Agrochernozeams (Belgorod Oblast)

M. A. Smirnova^{a, *}, A. N. Gennadiev^a, and Yu. G. Chendev^b

^a Lomonosov Moscow State University, Moscow, 119999 Russia

^b Belgorod State National Research University, Belgorod, 308015 Russia

*e-mail: summerija@yandex.ru

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Abstract—The short-range lateral variation of soil properties is a particular expression of the spatial soil variability and a non-directional short-periodic (in the range of a few meters) change in soil-profile features. Contrary to the soil cover pattern theory of discrete soil cover, the short-range variation of soil properties characterizes the soil cover continuum: the soil cover is presented as a field of various soil properties, and the boundaries of chosen ranges of soil properties may not coincide with boundaries of soil taxa. This study is based on soil data from three parallel transects (240 m long) laid on the watershed perpendicular to a 60-year-old shelterbelt and crossing it in their central part. The sampling step is 10 m on agricultural fields and 6 m under the shelterbelt. Features of the humus (the content of organic carbon in the 0–20 cm layer and the thickness of the humus horizon and profile) and carbonate (the effervescence depth, the carbonate content in the effervescence layer, and the horizon of maximal accumulation of carbonates) profiles are analyzed for 75 observation points. It is shown that the parameters of the humus and carbonate profiles of soils are characterized by periodic changes at intervals of 6–10 meters. The parameters of the humus profile are characterized by lower variation coefficients (<30%) than the parameters of the carbonate profile (>50%). The growth of trees on agrochernozeams (Haplic Chernozems (Aric)) for 60 years resulted in the formation of new taxonomic components (postagrogenic agrochernozeams (Haplic Chernozems)) characterized by a smaller lateral variation in soil properties as compared to plowed soils. Three soil types are specified within the studied area: agrochernozeams (64 points; Haplic Chernozems (Aric, Loamic, Pachic)); clay-illuvial agrochernozeam (7 points; Luvic Chernozems (Aric, Loamic, Pachic) and Luvic Chernic Phaeozems (Aric, Loamic, Pachic, Loamic, Pachic)); and clay-illuvial quasigley agrochernozeams (4 points; Luvic Stagnic Chernic Phaeozems (Aric, Loamic, Pachic)), including eight subtypes.

Keywords: variability of soil properties, pedodiversity, organic carbon, Central Russian Upland, Chernozems

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INTRODUCTION

Spatial variability of soils is their integral quality and an important essential characteristic. There are several variants of spatial variability of soil properties with emphasis on manifestation of (a) its direction (vector), (b) its periodicity, (c) its frequency and regularity of changes in directions, etc. Lateral variation in soil properties is a particular case of the spatial variability of soils. It is usually characterized by nondirectional short-period (in the range of first meters) changes in soil profile parameters, which are mainly caused by variations in lithological (texture), geomorphic (microtopography), and zoological (burrowing animals) factors. Differences between the approaches to study lateral variation of soils and soil cover patterns is important and should be taken into account for correct formulation of the tasks and choice of the methods to analyze empirical data on lateral variation of soil properties, though both approaches have a number of

common goals and methodological tools. According to Fridland, the author of the holistic doctrine of the soil cover pattern, its study implies understanding the type of filling the space with soil classification units, regularities of their alternation, combination, and evolution [23]. When studying lateral variation, the soil cover is represented not by classification taxa, but by a continuous field of particular soil properties, and the boundaries of their chosen ranges may not coincide with the boundaries of classification units. At the same time, data on the soil cover pattern may be used in the study of lateral variation and complement the results.

The identification of features and factors of lateral variation of soil properties contributes to the understanding of the origin of the structural and functional organization of the soil cover [10]. The study of lateral variation of soil properties is important from a practical point of view for the design of precision agriculture, differentiated fertilization, formation of an opti-

mal soil sampling network, etc. Various aspects of lateral variation are discussed in [17, 28, 34, 32].

It is considered that properties of chernozems are characterized by relatively slight lateral variation due to thick humus horizon, relatively simple soil profile, and low variability of soil-forming factors at short distances [23]. However, there are data on significant lateral variability in the properties of chernozems within small distances caused by natural factors. For example, the spatial variation of pH_{KCl} , hydrolytic acidity, humus content, and other properties has been revealed for leached chernozems based on the study of soils along 800-m-long transects with a sampling step of 30–50 m [9]. It is shown that the areas of leached chernozems with contrasting fertility are allocated to different elements of topography. A detailed study of leached chernozems (test plot of 0.3 ha) indicates that the spatial variability of nitrate nitrogen content reaches 78%, and that of phosphorus and potassium is less than 31% [11]. A strong variation in the detection depth of carbonates—from 0 to 180 cm—was found by Sorokina [19] for a watershed in Kursk oblast. The results of detailed soil survey of various areas in the chernozem zone are given in [2, 4, 19, 22, 24, 26, 27, 30, 31]. Nevertheless, data on short-term lateral variation of the properties of chernozems are insufficient, particularly taking into account the fact that each combination of physiographic conditions is characterized by its own local combinations of factors determining the spatial variation of soil properties, which requires more comprehensive study.

The aim of this work is to quantify the lateral variation in the parameters of humus and carbonate profiles of agrochernozems. It is based on data on the properties of 75 agrochernozems (6–10 m between testing points) on three parallel 240-m-long transects laid on a watershed and crossing a forest shelterbelt. The thickness of the humus horizon and of the humus profile, the depth of effervescence with 10% HCl, the C_{org} content in the layer of 0–20 cm, and the content of CO_2 of carbonates in the effervescing layers and in the layers with carbonate pedofeatures (if these two layers did not coincide) were determined at each site. The particular tasks were as follows:

- to characterize soil morphology along the transects and to apply descriptive statistics to soil properties;
- to identify and evaluate features of lateral variation of soil properties on the transects; and
- to map the soil cover of the test plot and describe characteristic features of the soil cover pattern.

OBJECTS AND METHODS

The Bondarev site is located in the south of the Central Russian Upland in Krasnoyarskiy district of Belgorod oblast near the boundary with Kursk and Sumy oblasts. The climate of the area is moderately continental; according to data of the weather station in

Belgorod airport (82 km to the south of the research site), the mean annual temperature is $+8.6^\circ\text{C}$, and the mean annual precipitation is 582 mm/year (for the period from 2012 to 2020). The hydrothermic coefficient by Selyaninov is 1.24, and the site is located in the wettest part of the forest-steppe of the Central Russian Upland.

The site is characterized by a subhorizontal surface slightly inclined to the south ($<2^\circ$). There is a meridional-stretched 40-m-wide forest shelterbelt consisting of 12 double rows of trees with a predominance of common ash (*Fraxinus excelsior*) accompanied by elm (*Ulmus minor*) and ash-leaved maple (*Acer negundo*) trees. The age of the trees is about 60 years (as determined by counting annual rings in tree cores). The adjacent agricultural fields are occupied by cereal and industrial crops, and soil treatment involves moldboard plowing and disking. The age of the plowland is at least 170 years [16]. At the time of the study, the corn was grown to the west of the shelterbelt and wheat to the east of it. The parent materials are represented by carbonate loesslike loams, and the groundwater depth is more than 8 m [13].

Three 240-m-long transects were laid on the test plot at a distance of 10 m from one another perpendicular to the shelterbelt (Fig. 1). Soils were sampled every 10 m on agricultural lands (30 points in each field adjacent to the shelterbelt) and every 6 m under the shelterbelt (15 points). The depth of bore holes varied from 1.5 to 3 m, depending on the location of the layer with morphologically pronounced carbonate neoformations. The indexes of the sampling sites included the number of the transect (1—northern, 2—central, and 3—southern), the location relative to the shelterbelt (F—shelterbelt, W—to the west of the shelterbelt, and E—to the east of it) and the number of the site on the transect (the numbers are given from west to east individually for each field and shelterbelts). For example, pit 2E-4 was laid on the central transect to the east of the shelterbelt 30 m from its edge (that is, site 4 on the transect on the field to the east of the shelterbelt).

Samples were taken from the upper layer of the humus horizon (0–20 cm) to determine the content of organic carbon (75 samples) by Tyurin's (wet combustion) method [1]. The content of carbonate carbon was determined in 90 samples taken at the boundary of soil effervescence with 10% HCl and in the layer, where carbonate pedofeatures were detected (the effervescence boundary usually corresponded to the upper boundary of the layer of pedogenic carbonates, so one sample was usually taken). The analysis was performed by the chromatographic method 1 h after the start of the reaction of soil suspension with 10% HCl solution added in excess into vessels tightly closed with rubber stoppers. The soils were diagnosed and classified according to [7].

The data were statistically processed in the Statistica program, the main statistical parameters were cal-

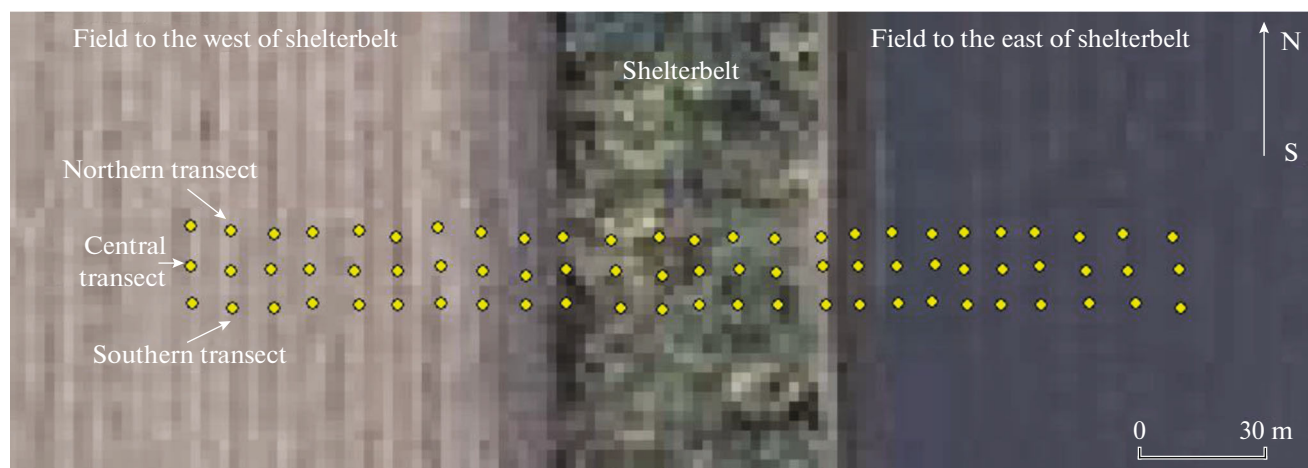


Fig. 1. A fragment of satellite image of the test area with sampling sites.

culated, hypotheses about the normality and lognormality of the distribution of the studied soil properties were tested (based on the Kolmogorov–Smirnov and Wilk–Shapiro criteria), and the Spearman correlation analysis was performed. The soil map was compiled by an expert method using the technique described in [25]. The boundaries between soil areas were based, among other parameters, on the results of superimposing maps of the humus profile thickness and the depth of effervescence constructed using the kriging method.

RESULTS AND DISCUSSION

Soil morphology. The profile of the studied soils consists of the following horizons. A thin (<3 cm) forest litter (only on the soil surface under the shelterbelt) is underlain by the agro-dark-humus PU horizon. It is dark gray, homogeneous, coarse cloddy in plowed soils and medium subangular blocky under the shelterbelt (index pa, the PU_{pa} horizon). The lower part of the PU horizon is very dense with evidences of horizontal layering. It is underlain by a well-structured subangular blocky to granular dark-humus AU horizon of the dark gray color. Its lower part in pits 1F-4, 2W-1, 2W-5, 2W-8, 3W-4, and 3W-9 effervesces with 10% HCl and may contain filamentous carbonates (index lc). The dark-humus horizon is underlain by the transitional to the middle clay-illuvial BI (pits 1W-2, 1W-3, 1W-7, 3W-1, 3W-2, 1F-2, 1E-4, 1E-5, 1E-8, 2E-1, and 3E-2) or carbonate-accumulative BCA (in the other pits) horizons. The BI horizon does not contain carbonates contrary to the BCA horizon and is characterized by thin films on the ped faces having a darker color than the intraped mass. A common feature of BI horizons is their strong disturbance by burrowing animals (mole rats), which is reflected in the heterogeneous color pattern with darker (material of the humus horizon) and lighter (material of the underlying horizons) mottles and variation in consistence (from loose to dense) within the horizon. The clay-

illuvial BI horizon is usually underlain by carbonate-accumulative BCA horizon (pits 1F-2, 1E-4, 1E-5, 1E-8, and 2E-1); less often, by a quasigley Q horizon (pits 1W-7, 3W-1, 3W-2, and 3E-2) or by parent material (C horizon, pits 1W-2 and 1W-3). The Q horizon is of olive color with ochreous mottles around large pores and cracks and, sometimes, with soft calcareous nodules (white eyes). The BCA and Q horizons are underlain by the soil-forming material.

Thus, taking into account the diagnostic horizons and features, soils of the transects are assigned to three types: agrochernozems (Haplic Chernozems (Aric, Loamic, Pachic), 64 sites), clay-illuvial agrochernozems (Luvic Chernozems (Aric, Loamic, Pachic) and Luvic Chernic Phaeozems (Aric, Loamic, Pachic), seven sites), and quasigley clay-illuvial agrochernozems (Luvic Stagnic Chernic Phaeozems (Aric, Loamic, Pachic), four sites). They are in turn specified into eight subtypes: clay-illuvial agrochernozems PU–AU–BI–C(ca), mycelium-carbonate (with carbonate pseudomycelium) clay-illuvial agrochernozems (postagrogenic) PU(pa)–AU–BI–BCAmc–Cca, mycelium-carbonate agrochernozems (postagrogenic) PU(pa)–AU–BCAmc–Cca, migration-mycelium agrochernozems (postagrogenic) PU(pa)–AU–AUlc–BCAmc, and quasigley clay-illuvial agrochernozems PU–AU–BI–Q–Cq. Soils described on the test plot correspond to soil units given in [8]: agrochernozems to typical chernozems, clay-illuvial agrochernozems to leached chernozems, and quasigley agrochernozems to meadow-chernozemic soils. Slightly contrasting combinations of typical and leached chernozems and meadow-chernozemic soils are typical for agricultural landscapes of the Central Russian Upland [2, 18–20, 22, 24], and the studied plot is thus representative.

Statistical parameters of humus and carbonate profiles of soils. Humus profiles of soils are formed by agro-dark-humus horizons (PU(pa)), dark-humus horizons (AU), and horizons transitional from dark-

humus horizon to middle-profile horizons (AU_{b,i} and Bl_{au}, AU_{b,ca} and BC_{Aau}). The thickness of the humus layer corresponds to the thickness of agro-dark-humus (PU(pa)) and dark-humus horizons (AU). Statistical parameters of soil properties are given in Table 1.

Soils of the test plot are characterized by very deep (up to 120 cm) humus horizons with a wide range of values (from 25 to 120 cm); the variation coefficient (C_v) is 28.0%. The average thickness of the entire humus profile (humus and transitional horizons) reaches 150 cm, and C_v is 19.3%, which reflects smaller lateral variation in the thickness of the humus profile as compared to that of the humus horizon. Similar results—smaller variation coefficients for the thickness of the humus profile in comparison with the thickness of the humus horizon of chernozems—are given by Fridland et al. [24] for chernozems of the Yamskaya Steppe. The reverse trend is revealed for chernozemic soils of the Kursk Experimental Station of the Dokuchaev Soil Science Institute [19]. The position of the boundaries of the humus horizon and the humus profile under the analyzed conditions is determined by a number of local factors, including the intensity of zoopedoturbation resulting in the disturbance of natural soil horizons [5, 33]. Therefore, it may be assumed that the differences in the rate of lateral variation in the thickness of the humus horizon and humus profile in the studied soils and from other published works may be related to different intensities of the burrowing activity of soil animals [6].

Mean and median thicknesses of the humus horizon and humus profile of agrochernozems, of clay-illuvial agrochernozems, and of soils under the shelterbelt are generally similar and are in the range of 55–60 cm (humus horizon) and 90–110 cm (humus profile). The increased thickness is typical for quasigley agrochernozems: the mean thickness of the humus horizon in them exceeds 90 cm, and that of the humus profile is greater than 129 cm. Despite the small sampling size of quasigley agrochernozems (four points), the variation coefficient in these soils is maximal for the humus horizon thickness (20.5%) and is close to that in agrochernozems (64 sampling sites) for the thickness of the humus profile (19.1% for agrochernozems and 18.7% for quasigley agrochernozems). Similar results—relatively increased thickness of the humus horizon and humus profile and maximum variation coefficients for meadow-chernozem soils (corresponding to quasigley chernozems according to [7])—were found for soils of the Kursk experimental station [19]: 95 and 143 cm with the variation coefficients of 19.5 and 13.3%, respectively.

In comparison with plowed soils, soils under the shelterbelt are characterized by a lower variation coefficient of the humus horizon thickness (16.3% contrary to 29.7 and 30.4%) and of the humus profile (14.8% contrary 16.7 and 21.7%). A similar trend was found for soils of the shelterbelt and adjacent plow-

lands on another test plot in Belgorod oblast (Gubkin district), where soil testing interval was equal for plowland and shelterbelt and there were 10 sampling sites in each [14]. Tree vegetation obviously favored homogenization of the soil properties.

The mean organic carbon content in the studied soils is 5.1–6.1%, and C_v is 16%. These are slightly lower values as compared to the mean C_{org} (6.2%) in agro-dark-humus horizons of soils of the Central Russian Upland [12]. The organic carbon content reaches maximum under the shelterbelt and in quasigley agrochernozems, which is related to more favorable conditions for humus accumulation as compared to other soils of the plot. Favorable factors in this case include the functioning of quasigley chernozems under slightly wetter conditions [31], which contribute to organic matter fixation in soils due to its slower decomposition [16].

The depth of pedogenic carbonates in the studied soils varies significantly from 30 to more than 250 cm. It increases from agrochernozems to clay-illuvial agrochernozems and quasigley agrochernozems; in the latter, carbonates were detected at only one site of the four studied sites. Soils of the plowland to the west of the shelterbelt are characterized by closer to the surface pedogenic carbonates and a larger variation coefficient (64.7%) as compared to soils under the shelterbelt and on the plowland to the east of it, where C_v is 29 and 43.4%, respectively. The mean depth of pedogenic carbonates in the analyzed soils is 60–90 cm, and their content varies from 1 to 3%. The depth of pedogenic carbonates in the studied soils exceeds that in typical chernozems of the central chernozemic region (40–60 cm). In addition, soils at all sampling sites do not contain carbonates from the surface, which is not typical for the soil cover of the Central Russian Upland [19, 27]. These specific features may be caused by the location of the test area in the wettest part of the Central Russian Upland, where the Selyaninov hydrothermal coefficient is 1.24.

Histograms of the thickness of the humus horizon, humus profile, and carbonate depth do not follow the normal and lognormal distribution, while C_{org} and CO_2 contents correspond to the normal distribution, so the use of the Spearman correlation analysis for them is appropriate. Its results show a direct significant ($p = 0.01$) relationship between the thickness of the humus horizon and of the humus profile (the correlation coefficient is 0.59) and the detection depth of pedogenic carbonates (the correlation coefficient is 0.43). The C_{org} content in the upper 20-cm layer is in positive correlation ($p = 0.05$) with the thickness of the humus horizon (the correlation coefficient is 0.28) and of the humus profile (the correlation coefficient is 0.25). The deeper the layer of pedogenic carbonates, the lower the content of carbonates in this layer ($p = 0.01$, the correlation coefficient -0.33).

Table 1. Statistical parameters of the properties of humus and carbonate profiles of agrochernozems at the test area

Property	Sampling	Statistical parameters					
		sampling size	mean	median	min	max	standard deviation
Thickness of humus horizon, cm	All sites	75	58.5	60	25	120	16.4
	Agrochernozems	64	56.7	55	25	100	14.8
	Clay-illuvial agrochernozems	7	55.7	60	50	60	5.3
	Quasi-gley clay-illuvial agrochernozems	4	92.5	85	80	120	18.9
	Plowland (to the west of shelterbelt)	30	61.0	60	35	120	18.1
	Plowland (to the east of shelterbelt)	30	57.3	55	25	80	17.5
	Soils under shelterbelt	15	56.0	50	40	70	9.1
Thickness of humus profile, cm	All sites	75	104.6	110	55	150	20.2
	Agrochernozems	64	104.4	110	55	130	19.1
	Clay-illuvial agrochernozems	7	91.4	90	70	120	16.78
	Quasi-gley clay-illuvial agrochernozems	4	129.7	134	100	150	24.22
	Plowland (to the west of shelterbelt)	30	113.1	120	70	150	18.89
	Plowland (to the east of shelterbelt)	30	98.0	100	55	130	21.28
	Soils under shelterbelt	15	100.7	100	80	130	14.86
C _{org} , %	All sites	75	5.56	5.57	3.83	9.92	0.88
	Agrochernozems	64	5.58	5.58	3.83	9.92	0.928
	Clay-illuvial agrochernozems	7	5.14	5.22	4.14	5.71	0.479
	Quasi-gley clay-illuvial agrochernozems	4	5.93	5.91	5.64	6.25	0.250
	Plowland (to the west of shelterbelt)	30	5.49	5.59	3.83	6.65	0.664
	Plowland (to the east of shelterbelt)	30	5.34	5.34	4.16	6.46	0.601
	Soils under shelterbelt	15	6.11	5.76	4.51	9.92	1.420

Table 1. (Contd.)

Property	Sampling	Statistical parameters					
		sampling size	mean	median	min	max	standard deviation
Depth of carbonates*, cm	All sites	71	79.0	80	30	170	27.6
	Agrochernozems	64	74.0	72	30	120	22.0
	Clay-illuvial agrochernozems	6	123.3	110	100	170	55.2
	Quasi-gley clay-illuvial agrochernozems	1	150	150	150	150	—
	Plowland (to the west of shelterbelt)	27	73.7	60.0	30	170	32.3
	Plowland (to the east of shelterbelt)	29	84.0	90.0	35	150	24.7
	Soils under shelterbelt	15	80.0	90	40	100	23.3
CO ₂ of carbonates in the effervescing horizon, %*	All sites	71	2.4	2.0	0.2	5.3	1.26
	Agrochernozems	64	2.3	1.9	0	5.3	1.25
	Clay-illuvial agrochernozems	6	3.7	3.6	2.4	4.4	0.73
	Quasi-gley clay-illuvial agrochernozems	1	1.9	1.9	1.9	1.9	—
	Plowland (to the west of shelterbelt)	27	2.3	2.0	0.2	5.3	1.42
	Plowland (to the east of shelterbelt)	29	2.7	2.6	1.1	5.3	1.13
	Soils under shelterbelt	15	2.1	1.8	1.0	5.0	1.17
CO ₂ of carbonates in the horizon with carbonate pedofeatures, %*	All sites	71	2.9	2.9	0.7	5.3	1.26
	Agrochernozems	64	2.9	2.9	0.7	5.3	1.29
	Clay-illuvial agrochernozems	6	3.7	3.6	2.4	4.4	0.73
	Quasi-gley clay-illuvial agrochernozems	1	1.9	1.9	1.9	1.9	—
	Plowland (to the west of shelterbelt)	27	3.0	2.9	0.7	5.3	1.23
	Plowland (to the east of shelterbelt)	29	3.0	3.1	1.1	5.9	1.19
	Soils under shelterbelt	15	2.8	2.9	1.0	5.3	1.50

*Soils with the absence of secondary carbonates (pits 1W-3, 1W-7, 3W-1, and 3E-2) were excluded from the calculations.

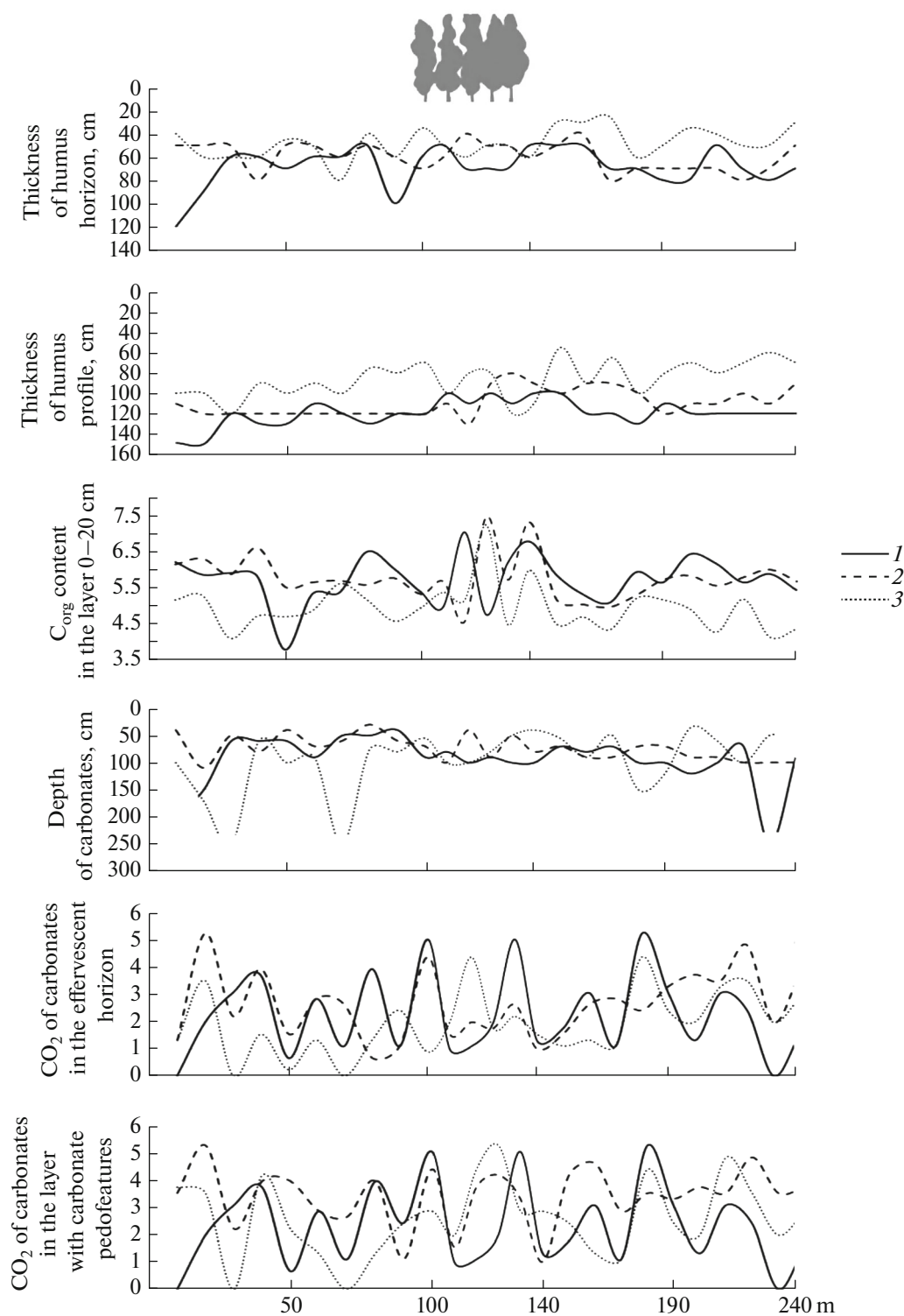


Fig. 2. Changes in soil properties along (1) northern, (2) central, and (3) southern transects.

Lateral variation in the properties of agrocherno-
zems. The diagrams of changes in soil properties along the transects (Fig. 2) show a tendency for periodic changes (alternation of increased and lower values) in the thickness of the humus horizon and of the humus profile, in the depth of effervescence, and in the con-

tents of C_{org} and CO_2 of carbonates with a period equal to the sampling interval (6–10 m). A similar regularity with a slightly larger step of 15–25 m is described in [21] for the contents of C_{org} and CO_2 in chernozems of experimental fields of the Kursk Research Institute of Agroindustrial Production (samples were taken on

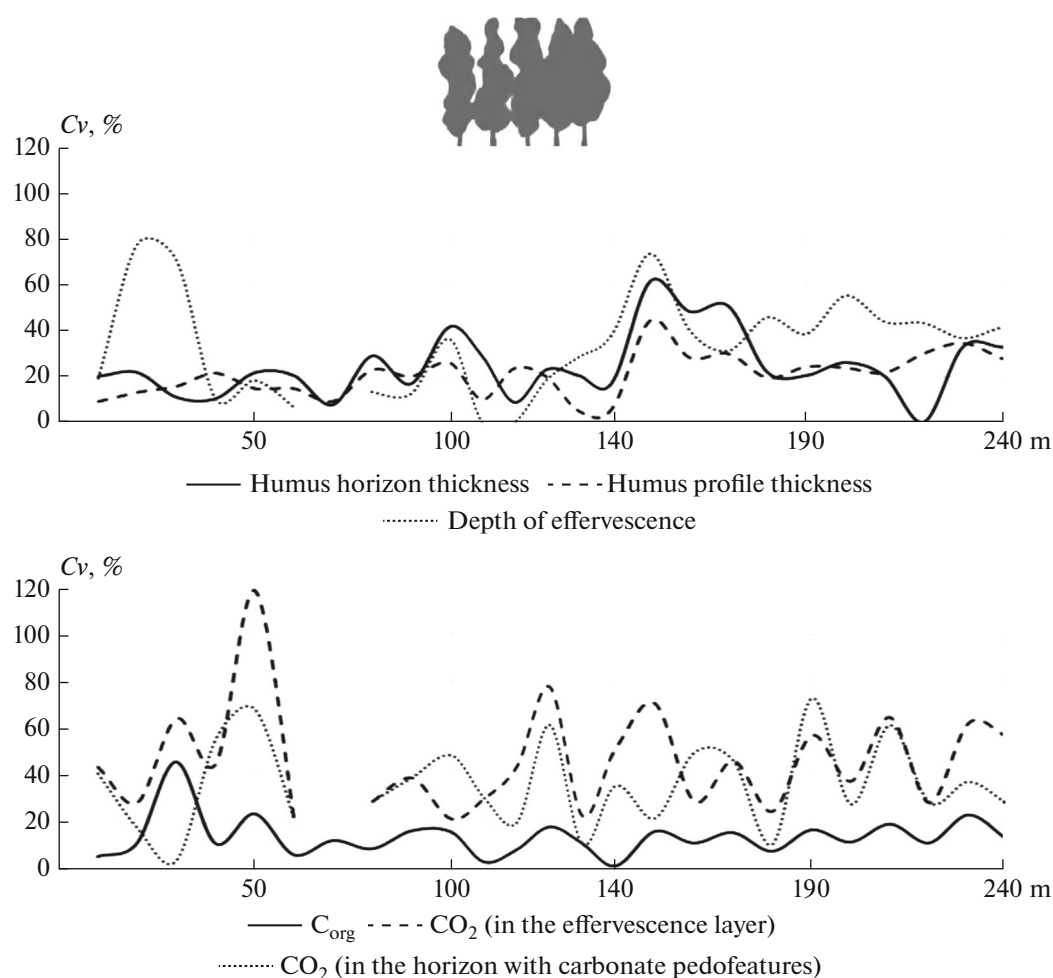


Fig. 3. Variation coefficients of soil properties in sampling series perpendicular to the transects (each variation coefficient is calculated for three sampling sites). Line breaks correspond to soils located 30 m to the west of the shelterbelt edge (secondary carbonates are absent at two of the three sites).

transects every 5 m). There are data [15] that quasiperiodicity in the C_{org} content in southern chernozems is observed for long (>800 m) transects with the sampling interval of 150 m. Since the spatial variability of properties can be detected at different scales [29], we argue that our data do not contradict the data by Sidorova and Krasilnikov [15], but characterize the variability of the organic carbon content at different spatial levels. We also believe that studies on longer transects may be performed with intervals greater than 6–10 m, corresponding to the appearance of quasigley chernozems with increased humus profile and often leached from carbonates.

According to detailed surveys of the soil cover in different parts of the Central Russian Upland, this area is characterized by combinations of typical calcareous, typical, and leached chernozems with different parameters of carbonate and humus profiles at short distances [2, 4, 19, 22, 24, 26, 27, 30, 31]. The sampling network with a step of 6–10 m approxi-

mately corresponds to the size of elementary soil areas on interfluvial of the Central Russian Upland [18, 20, 22, 31]. This may explain the revealed trends of periodic changes in the properties of humus and carbonate profiles of soils at the studied transects. Meadow-chernozemic soils with deep humus horizon and often without carbonates are allocated to the bottoms of large depressions and hollows; they occur more rarely than typical calcareous, typical, and leached chernozems. Their presence in the soil cover is characterized by greater spatial intervals (100–300 m).

Figure 3 displays variation coefficients of the studied morphological and chemical properties of soils. Each of the samplings for determining the variation coefficients includes three sites (one site from the northern, central, and southern transects), which form a series perpendicular to the transect direction. In total, 25 series characterize the test area.

The diagrams attest to the agreement of variation coefficients for different soil properties: a high vari-

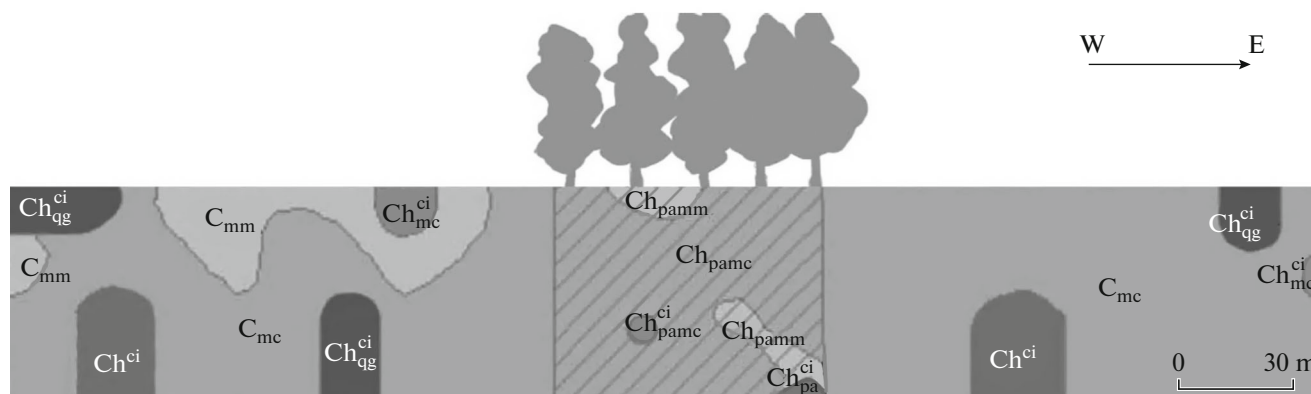


Fig. 4. Soil map of the test plot. Ch_{mc} —mycelium-carbonate agrochernozems, Ch_{mm} —migration-mycelium agrochernozems, Ch^{ci} —clay-illuvial agrochernozems, Ch_{qg}^{ci} —quasi-gley clay-illuvial agrochernozems, Ch_{mc}^{ci} —mycelium-carbonate clay-illuvial agrochernozems, Ch_{pamc} —mycelium-carbonate postagrogenic agrochernozems, Ch_{pamm} —migration-mycelium postagrogenic agrochernozems, Ch_{pamc}^{ci} —mycelium-carbonate clay-illuvial postagrogenic agrochernozems; Ch_{pa}^{ci} —clay-illuvial postagrogenic agrochernozem.

ability of any property (for example, of the humus horizon thickness) is accompanied by a high variability of the rest of the studied properties (the humus profile thickness, the effervescence depth, and the contents of C_{org} and CO_2 of pedogenic carbonates). The differences between closely located transect sites are greater for parameters of the carbonate profile than for those of the humus profile of soils. Variation coefficients less than 20% are typical for the organic carbon content (for 22 of 25 series); for other parameters, the coefficient <20% is detected only for 6–11 series. Variation coefficients >60% were determined for five series for the CO_2 content in the layer with pedogenic carbonates, for four series for the detection depth of carbonates, and for one series for the humus horizon thickness and the CO_2 content of carbonates in the effervescing layer. Most variation coefficients are within the range of 20–60% (except for the variation coefficient for the organic carbon content).

The soil cover of the test area. Figure 4 shows the soil map of the test area. Mycelium-carbonate agrochernozems are the predominant (background) soils, and other subtypes of agrochernozems occur are represented by strips. The sizes of soil areas decrease in the following sequence: mycelium-carbonate agrochernozems—mycelium-carbonate postagrogenic agrochernozems—migration-mycelium agrochernozems—clay-illuvial agrochernozems—quasi-gley clay-illuvial agrochernozems—mycelium-carbonate clay-illuvial agrochernozems—migration-mycelium postagrogenic agrochernozems—mycelium-carbonate clay-illuvial postagrogenic agrochernozems. The pattern of the soil cover is simple; soil areas usually have boundaries with no more than two other components of the soil cover.

In general, the soil map of the test area corresponds to the modern concepts of the soil cover of the Central

Russian Upland [2, 4, 19, 22, 24, 26, 27, 30, 31]. The size of the test area does not enable us to completely characterize the soil cover pattern. It can be supposed that it belong to the low-contrasting combination of the water-migration genesis of agrochernozems in background areas with clay-illuvial agrochernozems and quasigley clay-illuvial agrochernozems of irregular pattern (soil spottiness).

Our study indicates that the growth of tree vegetation on agrochernozems during 60 years have caused the appearance of new postagrogenic subtypes of agrochernozems in the soil cover. They differ from their plowed analogues by better structure of the humus layer and by greater thickness of the humus horizon and higher C_{org} content.

CONCLUSIONS

The parameters of lateral variation in the properties of agrochernozems have been identified for soils of watersheds in Belgorod oblast along three parallel transects spaced at 10 m from one another sampled with a step of 6–10 m (overall, 75 sampling points), crossing the 60-year-old shelterbelt in their center.

(1) The degree of lateral variation in the morphological properties of soils increases in the following sequence: thickness of the humus profile—thickness of the humus horizon—depth of pedogenic carbonates. The degree of lateral variation in the chemical properties of soils increases in the sequence: C_{org} in the upper 20-cm layer— CO_2 of carbonates in the layer with carbonate pedofeatures and in the layer of effervescence. The parameters of the humus profile are characterized by lower variation coefficients (<30%) than the parameters of the carbonate profile of soils (>50%).

(2) Lateral variation has a periodic pattern with intervals of 6–10 m for the thickness of the humus horizon and humus profile, in the depth of pedogenic carbonates, in the C_{org} content in the layer of 0–20 cm, and in the content of the CO_2 of carbonates in the layer of effervescence and in the layer with pronounced carbonate pedofeatures.

(3) The soil cover is transformed and consists of postagrogenic agrochernozems with a lower lateral variation in soil properties as compared to plowed soils under the 60-year-old shelterbelt. The soil cover of the test area under the cropland is characterized by a predominance of agrochernozems (64 sampling points), clay-illuvial agrochernozems (7 sampling points), and quasigley clay-illuvial chernozems (4 sampling points).

(4) The soil cover pattern on the studied test area is represented by low-contrasting combinations of the water-migration genesis of agrochernozems in background areas and irregularly occurring areas of clay-illuvial agrochernozems and quasigley clay-illuvial agrochernozems.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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