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DEGRADATION, REHABILITATION, AND CONSERVATION OF SOILS

Soil Development in Anthropogenically Disturbed Forest-Steppe Landscapes

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Abstract—The results of long-term studies of chernozem development in anthropogenically disturbed landscapes of the forest-steppe zone are discussed. Parameters characterizing the formation of the humus horizon of chernozems and the rate of this process are presented. Critical points and characteristic times of the formation of humus horizons are determined. The regeneration of soil properties as dependent on the degree of anthropogenic disturbance of chernozems is estimated.

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INTRODUCTION

At present, soil scientists have at their disposal considerable amounts of pedochronological data for different soil zones and regions [1–3, 6–8, 10]. These data form a solid basis for revealing the main regularities of the development of morphological and functional properties of soils at different stages of their ontogenesis and under the impact of changes in bioclimatic conditions. At the same time, there is a sharp deficit in empirically grounded quantitative estimates of the rates of reproduction and restoration of soil fertility characteristics, though such estimates are necessary for the proper planning of soil rehabilitation measures and for the monitoring of soil resources in anthropogenically disturbed landscapes.

The high energy potential of pedogenesis in the forest-steppe zone and the potentially high rates of many pedogenic processes in this zone were taken into account in the choice of the area for studying soil evolution in the anthropogenically disturbed landscapes. Field works were performed in 1996–2005. Their major result is a data bank of pedochronological data with more than 300 descriptions of particular soils developing on the anthropogenically disturbed surfaces in the forest-steppe zone. The studied objects reflect different stages of the restoration of forest-steppe soils. The initial analysis of obtained information was performed by the authors in a special monograph [5].

OBJECTS AND METHODS

Field studies were performed in the central chernozemic region of Russia and in the northwestern part of the forest-steppe zone of Ukraine. This vast area offers good possibilities to study soil formation on dated surfaces of different ages: from kurgans of the Bronze Age (about 4500 BP) to naturally overgrown surfaces of stripping rocks, on which the initial stages of soil formation (beginning from the zero moment) can be studied. The dating of anthropogenically exposed substrates was performed with the help of historical and archaeological methods. Information obtained by us in the field makes it possible to analyze the regularities of soil development for chronointervals from $n \times 10$ to $n \times 1000$ years.

The main method of the study is a comparison of newly formed soils in soil chronosequences with due account for the character of parent material, phytocenoses, and surface topography. The major attention was paid to the growth of the humus horizon in the studied soils. Its thickness at different stages of soil development was estimated with the help of nonlinear functions as suggested by Lisetskii [8].

RESULTS AND DISCUSSION

Soil development is a relatively slow and long-term process, so that its direct observation is impossible. To judge the character and rates of soil development, an efficient method of dated soil chronosequences developing from the same substrate is used; such chronosequences may be referred to as pedolithocombinations [3]. The soil profiles formed on dated surfaces and studied by us represent a chronosequence characterizing the development of chernozem on the loesslike loam under the forb–grassy vegetation (Fig. 1). Every particular model soil in this chronosequence reflects a certain stage of the morphological and functional development of the soil profile and is representative of a number of analogous objects studied by us since 1996. The profile of a typical chernozem on a long-term fallow was studied by us as a full-Holocene mature soil profile.

The following soil objects compose the studied chronosequence.

(1) Soil developed on the ground fill over a cellar in the village of Streletskoe of Belgorod district (Bel-

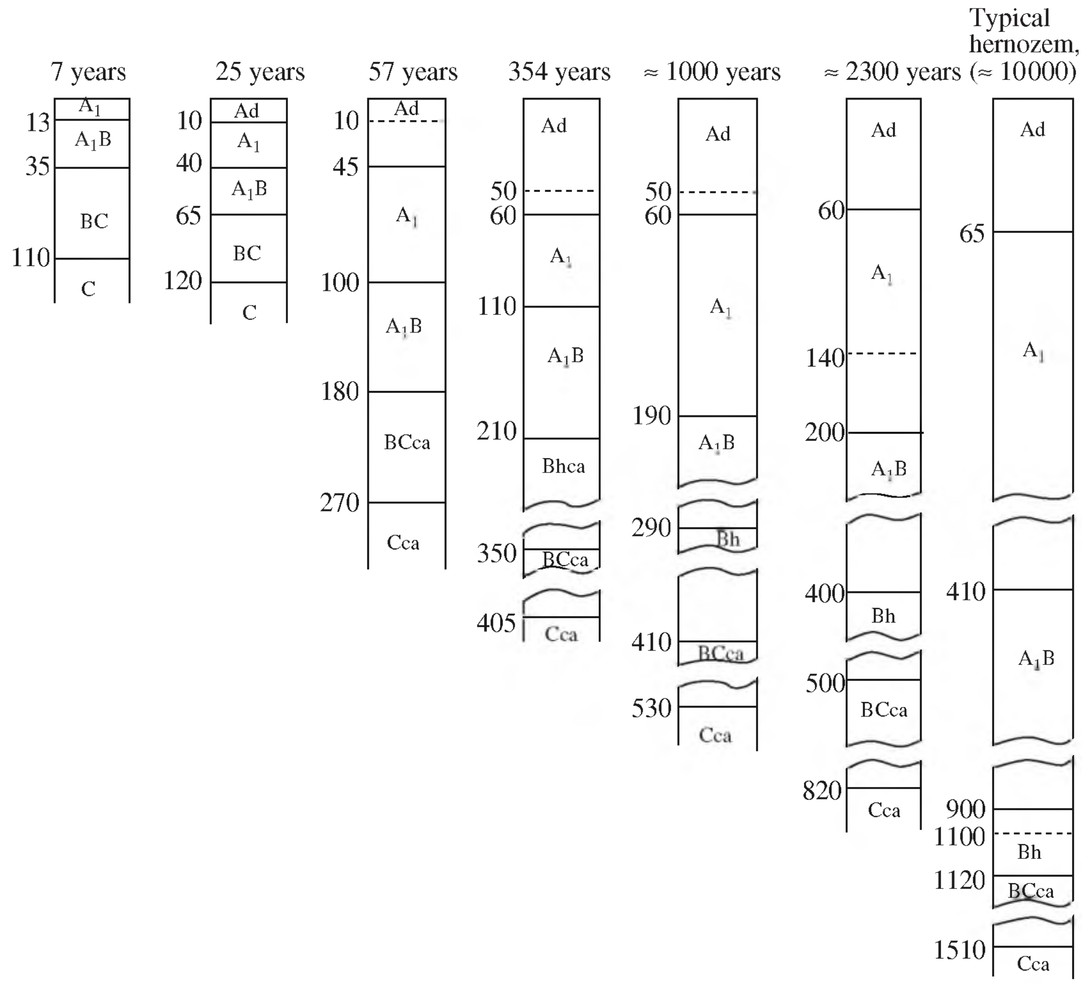

Fig. 1. Chronosequence of forest-steppe chernozems; the thickness of soil horizons is given in mm; dashed line indicates the upper boundary of effervescence from 10% HCl.

gorod oblast). This 7-year-old fill is overgrown by plants with a predominance of rootstock and bunch; the initial differentiation of the soil profile into genetic horizons is clearly seen in it (Fig. 1). The sod horizon has a fragmentary character; it is developed under dense tillering nodes of grasses. The humus-accumulative horizon of a brownish gray color is clearly distinguished; it is thin (0–13 cm) and contains the features attesting to the beginning of humus accumulation and the soil structuring (of coprogenic origin). Below, a transitional horizon of heterogeneous color and with loose crumb–granular structure is formed. The material of this horizon is processed by earthworms. Its lower boundary has a diffuse character. The features attesting to the illuviation of humus and clay particles can be seen in the underlying transitional (BC) horizon; this horizon has an indistinct prismatic structure and is penetrated by numerous humus "veins" along the paths of dead roots, which attests to the active accumulation of humus in situ. The roots of grasses penetrate to a depth of 30–35 cm, and their maximum amounts are seen in the uppermost 8 cm. At this stage of soil development, it is difficult to distinguish continuous boundaries of soil horizons (except for the A1 horizon that can be clearly distinguished from the underlying horizon). The localization of particular processes in the soil profile is relatively unstable, and the migration processes have a transient character. The strong topological variability of soil formation is typical of this initial stage of soil development: the most pronounced "micropedons" are seen under relatively dense nodes of grasses.

(2) Soil developed on the dam of the dried sludge pond of the Belgorod Cement JSC. The age of this soil reaches 25 years. Fescue and meadow grass predominate in the phytocenosis. The sod horizon (Asod) enriched in plant detritus is well pronounced; the thickness of humus horizon increases by two times, and its structure becomes more distinct. The A1B horizon has a well-shaped granular–crumb structure; coprogenic aggregates are evenly impregnated with humus, though the sorption of humic substances on the surface of peds predominates. The humus horizon is less compact in comparison with the underlying horizon. The strong

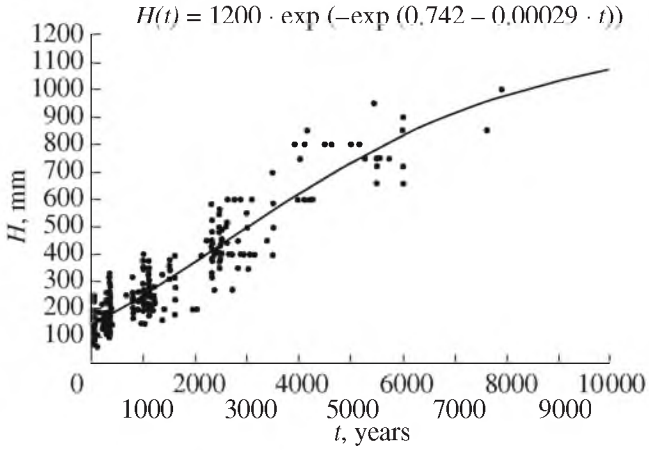

Fig. 2. Changes in the thickness of humus horizon (*H*) in forest-steppe chernozems of different ages (*t*).

compaction of the low soil horizons is explained by the application of heavy tractors during the dam construction. The illuvial BC horizon is also clearly pronounced.

(3) Soil developed on the bank of a defense ditch near the village of Shopino in Belgorod district of Belgorod oblast. This 57-year-old soil has the same horizon as the previous soil, but the total thickness of the soil profile has increased by almost three times. The rapid growth of the soil profile and an increase in the thickness of humus horizon is probably related to the establishing of a stable (stationary) level of phytomass production by the phytocenosis with well-developed herbs and grasses. The soil structure is well shaped; the A1 horizon has a crumb–granular structure; the A1B horizon, a granular–crumb structure; and the BCca horizon, a crumb–prismatic structure. Some redistribution of carbonates is seen in the soil profile: the depth of effervescence is 1 cm, and the BCca horizon contains calcareous pseudomycelium.

(4) Soil developed on a rampart near the village of B. Kul'baki in Belgorod district of Belgorod oblast. Defense ramparts were created in Belgorod oblast in the 17th century. The soils forming on them represent a chronological stage, during which the development of the soil humus profile proceeds under the stationary state of production–destruction processes; the structure and composition of soil organic matter in the upper horizons are also stabilized. The humus-accumulative horizon of the studied 354-year-old soil developed from the loesslike loam is intensely and evenly colored with humic substances; it has a clear boundary with the underlying B horizon. The line of effervescence is found deeper; the lower part of the illuvial horizon contains few calcareous nodules. In general, this soil profile some features typical of climax soils. A comparison between the soils developed in several decades (soil 3) and in several centuries (soil 4) shows a qualitative difference between them. The average rate of the soil profile development calculated for the 57-year-old soil is 5.1–5.4 mm/year; for the 354-year-old soil, it decreases to 1.1 mm/year.

(5) Soil on the rampart of the ancient Donetskii settlement in Kharkov oblast. The age of this soil is estimated at about 1000 years. It characterizes the stage of a relatively slow development of the soil profile; in this case, normal soil self-development of soil substitutes for the initial development of soil from the parent material [9]. A specific feature of the soil profile at this stage is a relatively diffuse character of the boundaries of soil horizos. A transitional A1B horizon with a somewhat lighter color in comparison with the A1 horizon is formed, and its thickness relative to the thickness of the A1 horizon decreases. In soil 4 (354 years), the ratio between the thicknesses of the A1 and A1B horizons is 1.1; in soil 5 (1000 years), it is 1.9. This may be related to a decrease in the rate of the vertical (down the soil profile) transformation of parent material by in situ humus-forming processes. Illuviation of humus into the B horizon leads to the development of the Bh horizon in the upper part of the illuvial layer. This horizon is distinguished by the presence of grayish tint; ped faces are covered by thin humus films; humus films also cover the walls of root paths. The depth of effervescence in the 1000-year-old soil is the same as in the 354-year-old soil, which may be due to the action of the biochemical barrier. Carbonate concentrations of 3–5 mm in diameter are abundant in the lower part of the illuvial horizon. The ratio of the thicknesses of soil horizons (A1 : A1B : (B + BC)) is 2 : 1 : 1. Thus, at this stage of soil formation, the thickness of the layer with active humus accumulation exceeds the thickness of the proper illuvial horizon by three times. The further development of this soil (see below) will be controlled by the relative enhancement of the eluvial–illuvial differentiation of the soil profile.

(6) Soil on the rampart of the ancient Bel'sk settlement (near the village of Bel'sk in Kotelkovskii district of Poltava oblast). The age of this soil is estimated at about 2300 years. The soil profile displays the features typical of mature chernozems. All the genetic horizons of chernozem are clearly developed in it, though their thickness remains lower than that in the full-Holocene chernozems. The A1 : A1B : (B + BC) ratio is 1 : 1 : 2, which is relatively close to the analogous ratio in the full-Holocene chernozem (1 : 1 : 1.5). The further development of the A1B and Bh horizon is due to the eluvial–illuvial differentiation of humus accumulation in the soil profile. The degree of soil leaching from carbonates remains low.

The development of morphological profiles of forest-steppe chernozems is accompanied by corresponding changes in their functional properties, including the properties of soil organic matter. Table 1 contains data on the humus state of soils in the studied chronosequence.

Table 1. Humus status of chernozemic soils developing in disturbed surfaces of different ages in the forest-steppe zone

Soil age, years	Horizon	Depth, cm	Humus	C_{org}	C_{lab}[1]		C_{ha}	C_{fa}	C_{humin}	C_{ha}/C_{fa}	Type of humus[2]
			% of the soil		% of the soil	% of C_{org}	% of C_{org}				
7	A1 + A1B	0–3.5	1.55	0.90	0.06	6.67	14.86	24.15	60.99	0.62	HF
25	A1	0–4	4.11	2.38	0.10	4.20	13.31	18.09	68.60	0.74	HF
	A1B	4–6.5	1.94	1.12	0.05	4.46	12.22	20.15	67.63	0.61	HF
57	A1	0–10	3.02	1.75	0.06	3.43	21.01	11.90	67.08	1.77	FH
	A1B	10–18	1.87	1.08	0.05	4.63	18.34	19.55	62.11	0.94	HF
354	A1	0–11	4.79	2.77	0.11	3.97	26.06	15.42	58.52	1.69	FH
	A1B	11–21	3.68	2.13	0.06	2.82	31.13	16.23	52.65	1.92	FH
≈1000	A1	0–19	3.89	2.25	0.06	2.67	33.54	20.66	45.80	1.62	FH
	A1B	19–29	3.22	1.86	0.06	3.23	19.71	16.69	63.61	1.18	FH
≈2300	A1	0–20	5.31	3.09	0.13	4.18	21.46	11.54	67.00	1.86	FH
	A1B	20–40	3.06	1.78	0.06	3.11	16.83	11.74	71.43	1.43	FH
FHA[3]	A1	0–41	4.12	2.38	0.06	2.52	33.72	15.13	51.15	2.23	H
	A1B	41–90	2.83	1.64	0.05	3.05	37.57	12.04	50.38	3.12	H

[1] Carbon of labile organic matter was determined by the method of M.A. Egorov in modification by B.A. Nikitin.
[2] Types of humus: (H) humate, (FH) fulvate–humate, and (HF) humate–fulvate.
[3] Full-Holocene analogue of newly formed soils.

As follows from this table, the humus content in the A1 and A1B horizons of newly formed soils approaches the background levels at the soil age of 25 years. However, the qualitative composition of soil organic matter in the young soils is different from that in the mature chernozems; in particular, the content of labile humus is increased, the degree of humification (C_{ha}, % of C_{org}) is low, and the soil humus belongs to the humate–fulvate type. Young soils are also characterized by the increased content of the fraction of nonhydrolyzable residue, which indirectly attests to the incomplete humification of plant detritus.

The analysis of data on the humus pools in the studied soils shows that they tend to increase from the young soil to the full-Holocene soil due to the increase in the thickness of humus horizons. At the same time, the content of humus (%) in the studied soils does not increase steadily. Thus, the humus content in the A1 horizon increases by 0.13–0.22%/year at the stage of young soils (7 and 25 years) that have the humate–fulvate type of humus. Then, by the age of 57 years, an increase in the thickness of the A1 horizon is accompanied by some lowering of the humus content in it. At the same time, this humus becomes more humate (the fulvate–humate type of humus is formed). From our point of view, these changes in the soil humus status are related to the transition of the young ecosystem to the stationary state of its functioning (with respect to the phytomass production and destruction processes). The stabilization of these processes at this stage of soil development eliminates the lag between the downward growth of humus horizons and the content and character of organic matter in them: the humus content in the A1 and A1B horizons, as well as the degree of humification, increases. Though the soils studied by us on the ramparts have an autochthonous origin, their humus state reflects some relic features (the assimilation of ancient sod material within the body of the ramparts by the newly formed soils).

An increase in the thickness of the A1 horizon at the expense of the A1B horizon in about 1000 years of soil development is accompanied by some lowering of the humus content and the C_{ha}/C_{fa} ratio. In the full-Holocene chernozem, this ratio in the A1 horizon is lower than that in the A1B horizon, which is explained by the long-term (>300 years) soil cultivation accompanied by some accumulation of fulvic acids in the plow horizon.

The analysis of soil chronosequences makes it possible to distinguish separate stages of soil development; the heterochronous development of particular pedogenetic processes is important [3]. Form our point of view, a significant impact on the particular stages of pedogenesis is exerted by the achievement of a relatively stationary state (with an equilibrium between production and destruction processes) by the ecosystem. An equilibrium between production and destruction processes facilitates the metamorphism of soil organic matter. At the stage of a rapid growth of phytomass production, the in situ accumulation of humic substances in the soil predominates over the processes of their translocation into the deeper horizons. This is typical of the first decades–centuries of soil development. The stabilization of phytomass production and destruction processes at the quasiclimax level predetermines the slow growth of the soil profile with a relative predominance of eluviation processes ($n \times 1000$ years). The specificity of this stage of soil development is the completion of soil horizonation; the sequence of soil horizons and their major diagnostic features correspond to those in the full-Holocene soil. In other words, the soil acquires a "mature" status.

Information on soil chronosequences is of great importance for the development and verification of mathematical models describing the development of major soil properties, including the soil humus status. Various models describing the formation of soil humus horizons and humus accumulation processes are well known [8, 10, 11]. As shown in [8], the development of soil humus profiles in automorphic soils during the Holocene generally corresponds to the development of growth processes in ecosystems having an S-shaped (sigmoid) pattern, which can be approximated by the Gompertz function:

$$H_t = H_{\text{S-LIM}}\exp(-\exp(a + \delta t)), \quad (1)$$

where H is the thickness of soil humus horizon, mm; $H_{\text{S-LIM}}$ is the limiting thickness of the humus horizon; a is a constant characterizing initial conditions of the process; δ is a coefficient characterizing the rate of the development of humus horizon; and t is the time (duration) of soil formation in years.

In the development of a model describing the growth of humus horizon in forest-steppe chernozems (leached, typical, and ordinary chernozems), we have use the whole data bank of pedochronological records with more than 300 soils of different ages (Fig. 2).

The value of $H_{\text{S-LIM}}$ was taken as the limiting (or equilibrium) thickness of soil humus horizon under given bioclimatic conditions.

The fast settling of plants on the exposed surface of fresh loesslike material is accompanied by the fast growth of plant productivity; the amount of plant residues entering the soil increases. The efficiency of humification and fixation of the products of humification in the profile of the young soil is high; therefore, the humus horizon is quickly reproduced in the zone with the maximum input of plant litter (including root litter) (0–20 cm). This specificity of the early stage of soil development does not allow us to use corresponding data together with the data obtained at later stages of soil development for a single model of the development of soil humus profiles. Therefore, the data obtained during the first decades of soil development (0–60 years) were considered separately.

The analysis of earlier published data on soil formation on recently exposed surfaces [4] allows us to suppose that this early stage of soil development has a number of specific features. Thus, the intensity of the formation of particular soil properties at this stage of soil development is largely controlled by interactions between the biota and the substrate. This is the main

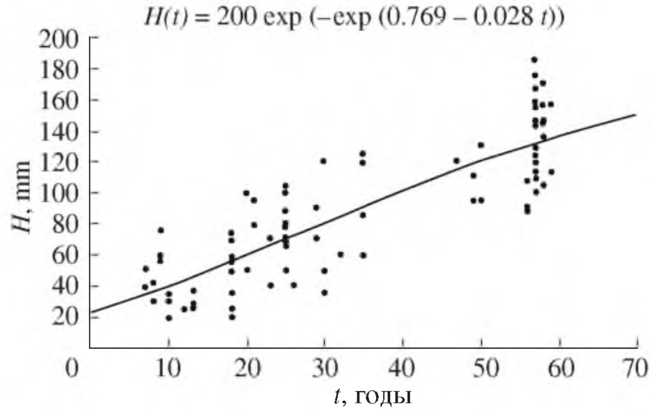

Fig. 3. Changes in the thickness of humus horizon (H) with time t in the course of the initial soil formation on disturbed surfaces.

reason for the polyvariant character of soil development at this stage. Many elementary pedogenetic processes in the young primitive soils ($n \times 10$ years) are much more active than the same processes at later stages of soil development. Hence, it is hardly possible to describe the trend of the recent soil formation with the help of a model with constant parameters. It seems that a model reflecting a gradual increase in the rate of pedogenesis (proportionally to the increase in the input of plant residues in the course of the phytocenosis development) should be applied in this case. Then, after reaching the peak of intensities of pedogenetic processes, the model should describe a gradual attenuation of the rate of pedogenesis corresponding to the equilibrium between the input and decomposition of organic matter in the zone of the maximum processing of the substrate by the soil biota. Thus, an S-shaped model seems to be appropriate. If we assume that the major regularities of soil development are preserved during all the stages of soil evolution, then the Gompertz model can be applied.

A significant problem is the selection of appropriate empirical coefficients for the model. In particular, it is necessary to substantiate the limiting (maximum) thickness of the humus horizon that may be formed during the first stages of soil development (until the transition to a slow growth of the humus horizon in the interval from $n \times 100$ to $n \times 1000$ years. As follows from our data, this thickness may be estimated at 200–250 mm, which correspond to zone of maximum saturation of the soil with plant roots. Grassy cenoses are favorable for the quick reproduction of the humus profile of chernozems within the zone of active humus accumulation; after the rapid growth of the humus horizon, the intensity of this process should decrease considerably.

Figure 3 contains the curve and the equation describing it (the Gompertz Eq.) for the initial (recent) stage of soil formation. Note that the parameters of the

Table 2. Average rates of the development of humus horizons in forest-steppe chernozems upon different degrees of their anthropogenic disturbance (numerator – mm/year; denominator – t/ha (at the bulk density of 1.2 t/m^3))

Conditions of soil formation	Degree of disturbance of the initial humus horizon (residual thickness of the disturbed humus horizon H_A, part of the initial thickness H)			
	weak (H_A = 1.0–0.8H)	moderate (H_A = 0.8–0.5H)	strong (H_A = 0.5–0.2H)	very strong (H_A = 0.2–0H)
Favorable	$\frac{0.06}{0.72}$	$\frac{0.11}{1.32}$	$\frac{0.14}{1.68}$	$\frac{4.78}{57.36}$
Medium	$\frac{0.05}{0.60}$	$\frac{0.09}{1.08}$	$\frac{0.12}{1.44}$	$\frac{2.31}{27.72}$
Unfavorable	$\frac{0.04}{0.48}$	$\frac{0.07}{0.84}$	$\frac{0.09}{1.08}$	$\frac{1.03}{12.36}$

Note: Soil-forming conditions were estimated on the basis of a matrix showing the dependence of the soil-forming potential on the particular substrate and phytocenotic conditions [5].

model are changed (compare Figs. 2 and 3); changes in the a coefficient are insignificant, whereas the δ coefficient is increased by 100 times. This attests to a much more active growth of the humus horizon during the initial stage of soil formation.

The study of the obtained equation gives us the following results. The rate of the humus horizon formation during the initial stage is 1.5–2.1 mm/year with a maximum in the 28-year-old soil. The stabilization of this process begins at the soil age of about 60 years. In that time, the transformation of major processes responsible for the growth of humus horizon takes place: a predominantly in situ humus formation in the zone of maximum accumulation of humus is replaced by the eluvial–illuvial assimilation of the lower-lying parent material. This period of soil development is relatively short (in comparison with the entire full-Holocene range), and its length does not exceed 100–200 years. The model suggests that the period, for which the dynamics of soil humus horizon should be described be the equation of "slow growth," should be from 70 to 170 years. Thus, the formation of the humus horizon in forest-steppe chernozems during the recent soil development can be described by the following system of equations:

$$\begin{cases} H_t = 200\exp(-\exp(0.769 - 0.028t)), \ (t < 70) \\ H_t = 1200\exp(-\exp(0.742 - 0.00029t)), \ (t \geq 70) \end{cases} \quad (2)$$

The modeling of this process makes it possible to determine critical points in the soil ontogenesis. These critical points correspond to the alteration of the modes of soil development. According to Eqs. (2), they are observed at the age of 60–70 years (the transition from the stage of fast growth of the humus horizon to the stage of its slow growth) and at the age of about 6000 years (the transition to the final quasiclimax stage of soil development).

The most important theoretical problem in the development of the strategies of soil rehabilitation is the determination of length of necessary periods (norms) of restoration of soil properties. In particular, this is important for rehabilitation of eroded soils. Such estimates should be differentiated with respect to the particular genetic soil feature to be restores and to the degree of soil erosion. In an earlier study [8], it was argued that the stages of soil development from "fresh" parent material could be analogized with the stages of restoration of eroded soils (provided that the intensity of matter and energy inputs to the eroded soils will be no less than that in the natural ecosystems). Taking into account Eqs. (2), we can calculate the potential rate of the development of soil humus horizons with due account for the initial degree of disturbance of eroded soils (Table 2).

Calculations according to the mathematical models describing the intensity of soil development under favorable and unfavorable edaphic conditions make it possible to substantiate the norms of soil fertility reproduction, which is important for the proper organization of agricultural landscapes, including erosion control measures. The stronger the degree of soil disturbance (the farther the soil from the equilibrium status),, the higher the rate of regeneration processes. This regularity is illustrated by the plot showing the dependence of the rate of humus horizon formation in disturbed forest-steppe chernozems on the degree of maturity (residual thickness) of the humus horizon (Fig. 4).

Soil reproduction (restoration) is a process that can be controlled and optimized to achieve its high efficiency and high rates of restoration of soil properties, particularly at the early stages of soil formation. Taking into account a considerable decrease in the rate of pedogenetic processes upon the achievement of a relative functional maturity by the soil, the restoration of chernozems with the residual thickness of humus horizon above 0.2 $H_{S\text{-}LIM}$ would require considerable time spans; long-term rehabilitation measures should be undertaken

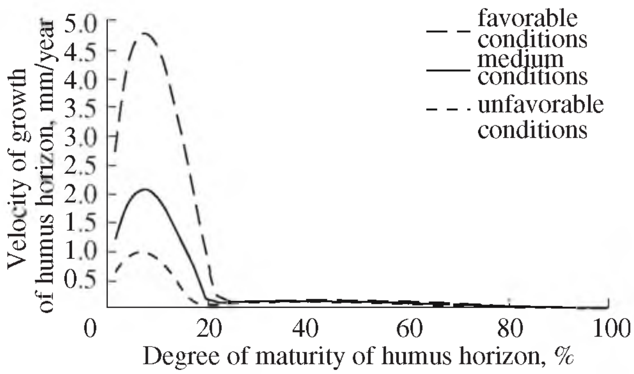

Fig. 4. The velocity of humus horizon formation in forest-steppe chernozems as dependent on the degree of maturity of humus horizon and the conditions of soil formation.

CONCLUSIONS

(1) Soil ontogenesis is a nonlinear process characterized by a complicated sequence of nonequilibrium dynamic transitions toward the quasiclimax state. Ontogenesis of soil as a bio-abiotic body can be described by the models of growth typical of the biological and ecological systems. Thus, the development of the major characteristic feature of chernozemic soils—the thickness of their humus horizon—proceeds through several stages controlled by different mechanisms: a predominance of the in situ accumulation of humus during the initial stage of quick growth is replaced by a predominance of slow eluvial–illuvial process affecting the redistribution of soil humus.

(2) A model describing the main trends in the development of humus horizons of chernozems has been suggested. On its basis, characteristic rates of this process under different soil-forming conditions have been calculated. The modern rate of the growth of humus horizons in the full-Holocene mature chernozems of the forest-steppe zone is about 0.04 mm/year; this rate cannot compensate for the loss of humus in the cultivated chernozems. However, during the initial stages of soil development (up to several decades), the rates of growth of the humus horizon are two orders of magnitude higher than those in mature soils. This attests to the high capacity of natural geosystems to restore the necessary regime of functioning of soil as their most important component.

(3) Soil formation on the recently exposed parent material is one of the most important regeneration processes in natural geosystems. In contrast to the Holocene pedogenesis, the recent soil development is characterized by the absence of the initial stage of slow development and by the accelerated character of soil processes at the initial stage. After several decades, the rates of soil processes sharply decrease. Critical points corresponding to changes in the mechanisms and rates of pedogenesis have been established on the basis of the analysis of the models of growth of soil humus horizon in chernozems. These points (intervals) are observed at the soil age of 60–70 years (the transition from the initial stage of rapid growth the stage of slow growth) and about 6000 years (the transition to the quasiclimax stage of soil development under given environmental conditions).

(4) Empirical substantiation of the rates of soil reproduction (restoration) is important from the viewpoint of the rational management of soil resources. On the basis of adequate estimates of the rates of soil formation in chernozemic soils subjected to different degrees of erosion, the norms of their rehabilitation can be established. It is important that the rates of soil restoration increase with an increase in the degree of soil disturbance (e.g., in the course of erosion). However, in calculation of allowable erosional losses, the major attention should be paid to the soil potential to compensate for these losses without a significant deterioration of the soil functioning rather than to rate of the natural reproduction of soil fertility.

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REFERENCES

1. A. L. Aleksandrovskii and E. I. Aleksandrovskaya, *Evolution of Soils and the Geographical Environment* (Nauka, Moscow, 2005) [in Russian].
2. A. L. Aleksandrovskii, *Evolution of Soils of the East-European Plain during the Holocene* (Nauka, Moscow, 1983) [in Russian].
3. A. N. Gennadiev, *Soils and the Time: Models of Development* (Mosk. Gos. Univ., Moscow, 1990) [in Russian].
4. P. V. Goleusov, "Soil Formation under Different Combinations of Substrate and Phytocenotic Conditions in the Forest-Steppe Zone," Pochvovedenie, No. 9, 1050–1060 (2003) [Eur. Soil Sci. **36** (9), 937–945 (2003)].
5. P. V. Goleusov and F. N. Lisetskii, *Reproduction of Soils in Anthropogenic Forest-Steppe Landscapes* (Belgorod, 2005) [in Russian].
6. I. V. Ivanov and E. D. Tabanakova, "Changes in the Thickness of Humus Horizons and the Holocene Evolution of East European Chernozems (Mechanisms, Factors, and Regularities)," Pochvovedenie, No. 9, 1029–1042 (2003) [Eur. Soil Sci. **36** (9), 917–930 (2003)].
7. I. V. Ivanov, *Evolution of Soils in the Steppe Zone during the Holocene* (Nauka, Moscow, 1992) [in Russian].
8. F. N. Lisetskii, "Spatial–Temporal Organization of Agrolandscapes" (Belgorod, 2000) [in Russian].
9. V. O. Targulian, "Development of Soils in Time," in *Problems of Soil Science* (Nauka, Moscow, 1982), pp. 108–112 [in Russian].
10. J. G. Bockheim, "Soil Development Rates in the Transantarctic Mountains," Geoderma **47** (1–2), 59–77 (1990).
11. J. W. Harden, "Soil Development on Stable Landforms and Implications for Landscape Studies," Geomorphology **3** (3–4), 391–398 (1990).