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AGROGENETIC EVOLUTION OF ARABLE CHERONEZOMS IN THE AREA BETWEEN THE PRUT AND NISTER RIVER: STAGES, TRENDS

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Abstract

The agrogenetic evolution of arable chernozems in the area between the Prut and the Dniester is examined through the prism of the genetic-evolutionary chain "elementary factors↔regimes↔pedogenetic processes↔soil" taking into account the changes induced in its components by the inclusion of soils in the agricultural regime. In such an approach, agrogenetic pedogenesis is examined through the prism of intercalated interdependent and interdetermined interactions induced by the use of soils in the agricultural circuit and climate change. In this context, the agrogenetic evolution of arable chernozems is genetically determined and the driving force of its development are the functional changes occurring in the organic matter system of soils.

Key words*: agrogenetic evolution, organic matter system, bioenergetic resources, energy potential, morphogenetic profile, humiferous profile.*

INTRODUCTION

The inclusion of soils in the agricultural circuit inevitably leads to changes in landscape conditions, and consequently in the soils as their basic component. In this context, it is unanimously recognized that the intensification of the agricultural production process has involved an anthrogenic-transformed trend in the evolution of soil resources, the proportions and meaning of which are determined by the regional bioclimatic and landscape conditions materialized in the type of pedogenesis and the initial state of the soils.

The processes of agrogenic transformation of soils, their functions and ecosystem services came into the attention of research in the seventies and eighties of the last century, being examined, in most cases, through the prism of soil degradation processes and the development of processes induced by agricultural use, especially by their cultivation, without taking into account the evolution of the pedogenetic environment determined by the intercalated action of natural and technoanthropic factors manifested in the pedogenetic (hydric, aeration, thermal) and pedofunctional (aerohydric, hydrothermal, oxidation-reduction, biological) regimes. Unidirectional changes in the pedogenetic process and soil functioning led to a unidirectional reduction in the natural fertility of soils, which led to the promotion of agrotechnical and agrochemical measures to increase "economic fertility" based on the simplistic agronomic approach to soil fertility, which is reduced to the intensification of work and the increase in the amounts of mineral fertilizers administered. The intensification of anthropogenic inputs led to increased yields under conditions of unidirectional reduction in soil fertility - a phenomenon that does not fit into the basic principles of the theory of pedogenesis. The evaluation of the anthropogenic-natural chernozem pedogenesis process through the prism of the "neodocuceavis triad" factor→processes→soil implied the conclusion that the reproduction of chernozem as a soil type under conditions of tillage is impossible (Gerasimov, 1983). The factorial-processual analysis of the chernozem process in the Carpathian-Pontian-Danubian space has highlighted a large group of natural and anthropogenic pedogenetic processes that manifest themselves in the intensification or inhibition of chernozem typogenetic processes (Lebedeva et al., 2013). At the same time, these lead to changes in the mechanisms of integration and structural-functional organization of soil matter (Jigău, 2003). The pedogenetic effects induced by these processes materialize in some parameters of the pedogenetic and pedofunctional properties and regimes, as well as in features that have no anthropogenic analogues within the chernozem type of soil formation (Butenko et al., 2025; Cheverdin et al., 2016). Thus, the processes induced by the anthropogenic factor play an important role in the unidirectional increase in chernozem pedogenesis in the upper Holocene materialized in a new distinct phase - anthropopedogenesis - within the anthropo-natural trend of evolution of soils, soil cover and biopedoclimatic framework.

In this context, in a series of more recent publications the evolution of arable chernozems is examined through the prism of the neo-docuceavis triad (factors → elementary processes → soil (functions)) taking into account the evolution of pedogenetic and pedofunctional regimes as a result of the modification of the pedogenetic environment induced by the intercalated unidirectional impact of anthropopedogenesis and climate change (Jigău et al., 2018; Jigău, 2019; Jigău et al., 2023): factors ↔ regimes ↔ elementary↔ processes↔soilanthrofactors↔anthroregimes ↔anthroelementary↔processes↔ anthrosols

In such an interpretation, the interdetermined and interdependent interactions between the natural and the anthropogenic components are taken into account, which determine the meaning and intensity of the integrated process on agrogenetic pedogenesis, within which the ratio between typogenetic and anthropogenetic processes is determined by the concrete landscape conditions.

MATERIALS AND METHODS

The conceptual-theoretical framework of the present research is provided by the biophysical concept of pedogenesis according to which pedogenesis is the integrative product of the interdetermined and interdependent interaction of the constitution and integration of the physical, chemical, physico-chemical and biological subsystems of the soil ecosystem within the genetic-evolutionary chain: factors/ anthropofactors → regimes/anthroporegimes → processes/anthropoprocesses → soil/ anthrosol. Through this prism of ideas, the evolution of the soil ecosystem involves two distinct phases: a) the constitution of the routine (physical) soil system; b) the constitution and evolution of the soil ecosystem (Jigău et al., 2023). The constitution of the routine (physical) soil system is determined by the abiotic processes of transformation and organization of abiotic components (solid, liquid, gaseous) with the formation of the pedolithic profile, the structural organization of which ensures favorable conditions for the development of the living phase.

The constitution of the soil ecosystem is determined by the biologization of the pedomatrix with the formation of the biopedomatrix and its modeling by living organisms in accordance with their own needs (Florea et al., 2014; Florea, 2016; Kleber et al., 2007).

Through this prism of ideas, pedogenesis is a biophysical category and for its evaluation it is recommended to apply the parameters of physical and biological properties as well as the chemical and physico-chemical parameters related to them. In this context, in our research, the [agrogenetic system] is used as an integrative index of physical parameters and the [bioenergetic system] is used as an integrative index of biological parameters.

The conceptual methodological framework of the present research is ensured by the principle of the unity of the chernozem pedogenetic process in the natural regime and in the anthropo-natural regime. In this context, the evolution of chernozems in the space between the Prut and the Dniester in the anthropo-natural regime is determined by the complex of chernozem typogenetic processes (formation and accumulation of humus; aggregation-structuring of the soil mass; migration of carbonates) of biologization of abiotic matter and agrogenetic (mineralization of organic matter, dehumusification, dehumification, destructuring) of debiologization of the biopedomatrix (Aksenova, 2022).

The intercalated development of these two groups of processes materializes in the interdependent and interdetermined interaction of the pedofunctional system [bioenergetic system] ↔ [aggregate system].

To evaluate the parameters of the bioenergetic system, the indices of the composition of the organic substance system and the humic system determined by the V. I. Tiurin method were used, and to evaluate the aggregate system, the indices of the structural-aggregate composition determined by the Savinov method were used (Kaurichev, 1980).

RESULTS AND DISCUSSIONS

In the present research, the evolution of arable chernozems under agrogenesis conditions is examined through the concept of genetically determined modification of chernozem typogenetic processes as a result of transformations in the system factors → regimes → elementary processes → soil as a result of the inclusion of lands in the agricultural circuit.

Through the laws of pedo-ecological relations (factors ↔ soil), the inclusion of chernozems in the agricultural circuit with all the related effects (substitution of natural vegetation with agrophytocenoses, deterioration of the "steppe litter" layer and the humic detritus layer, intensification of the degree of aeration of the arable layer, etc.) led to changes in the volume, composition and dynamics of the cycle of organic and biophilic substances in soils (Bruun et al., 2015).

The specified processes to a small extent affect the basic morphometric indices: the thickness of the humus layer (Am+Bm), the thickness of the humus-accumulative horizon (Am), the thickness of the humification-active transition horizon (Bm) (Table 1).

From the Table 1 presented, we note that during about 115 years the specified parameters have not undergone significant changes and the attested differences fall within the margin of error and, probably, are subjective in nature.

At the same time, however, there is a significant change in the thickness of the active root layer, which is caused, in our opinion, by the predominant concentration of nutritional elements in the upper and middle segment of the arable horizon. This entails a series of consequences manifested both in the quantity, establishment and dynamics of crop yields and in the meaning and intensity of the processes that take place in the "soil-plant" ecological system.

Table 1. Evolution of morphometric indices of chernozems in the area between the Prut and Dniester rivers in the post-Docuceavist period (1898-2011) (Jigău, 2023)

The soil	The soil	Morphometric index values					
		V.V. Docuceaev, 1898		I. A. Crupincov, 1988		Jigău, 2011	
		M	Max	M	Max	M	Max
Typical moderately humus-rich and leached black soils	Thickness of the humus layer (Am+Bm), cm	91	137	96	125	93	133
	Thickness of the humus-accumulative horizon (Am), cm	43	51	42	47	42	49
	Transition horizon thickness (Bm), cm	41.0	96	40	78	42	91
	Thickness of active root layer, cm	58	72	48	71	31	60

The concentration of crop roots in the upper and middle segment of the arable horizon has led to a reduction in the share of the edaphic volume of chernozems (85-95 cm) utilized by crop plants. As a result, the arable horizon is prone to depletion and the concentration of the root system in it significantly increases the degree of vulnerability of agroecosystems to drought. In a pedogenetic and functional context, this implies a significant reduction in the role of the root mechanism in the aggregation-structuring of arable chernozems.

At the same time, this implies a unidirectional reduction in bioenergetic reserves in the subarable segment (AmBm+Bm) of the arable chernozem profile. In addition, the increased degree of dynamics of the aerohydric and hydrothermal regimes, characteristic of the upper segment of the soil profile, leads to an increase in the share of the mineralization process within the integral process of mineralization-humification of organic residues and a reduction in the amounts of newly formed humus (Table 2).

Table 2. Composition of the organic matter system of arable chernozems under various maintenance conditions (layer 0-30 cm)

Mode of maintenance	Total organic matter content, %	Composition of the organic matter system, % of the total organic matter content in the soil		
		Humus	Non-humified organic matter	Mobile humic substances extracted in 0.1n NaOH
Leached clayey loam chernozem				
Hayfield	7.94	73.8	15.5	10.5
Lightly overcultivated arable land	4.98	83.9	7.2	8.9
Moderately overcultivated arable land	4.06	88.1	6.1	5.8
Heavily overcultivated arable land	3.29	93.7	2.9	3.4
Typical moderately humus-rich clayey loam chernozem				
Forest strip (47 years)	5.84	78.8	12.8	8.4
Fallow land (16 years)	5.39	71.1	13.7	10.2
Lightly overcultivated arable land	3.68	92.8	1.4	5.3
Moderately overcultivated arable land	3.08	94.8	0.9	4.3
Heavily overcultivated arable land	2.36	96.2	0.7	3.1
Typical weak humus-rich clayey loam chernozem				
Hayfield	5.91	77.1	14.5	11.4
Lightly overcultivated arable land	3.86	85.8	6.6	7.6
Moderately overcultivated arable land	3.00	90.7	4.5	4.8
Heavily overcultivated arable land	2.71	92.4	4.2	3.4
Clayey carbonate chernozem				
Wasteland	4.86	83.8	9.1	7.1
Weakly overcultivated arable land	3.02	88.9	4.3	6.8
Moderately overcultivated arable land	2.58	93.6	2.3	4.1
Heavily overcultivated arable land	1.83	95.3	1.1	3.6

From the table presented we can see that the use of chernozems in the agricultural circuit has led to the establishment of the overcultivation process in them, which involves changing the meaning and intensity of the overcultivation process, which involves changing the meaning and intensity of the chernozem pedogenesis process in conditions of pronounced deficit of bioenergetic resources. The quantity of the latter is reduced by about 1.6 times in slightly overcultivated soils, by 1.6-1.9 times in moderately overcultivated ones and by 2.2-2.7 times in strongly overcultivated soils.

From the perspective of the concept of "energy potential of soil organic matter", changes in the composition of the organic matter system imply a unidirectional change in the ratio between the components responsible for the share of three different forms of energy contained in the organic matter system: difficult to access contained in stable-inactive humic substances); moderately accessible (potential-active) contained in labile humic substances and microbial biomass; easily accessible (active) - the energy of non-humified organic matter (Masutenko, 2003).

In the context of the above, we mention that each component of the organic substance system has a certain role in its functioning and stabilization.

From the perspective of the concept of "energy potential", the fraction of stable humic substances (which has the major share in the composition of the humic substance system) ensures the stabilization of the "carcass" of the organic substance system, but also the development of the spatial framework for the localization and implementation of the functioning processes of the organic substance system.

Labile humic substances enriched with nitrogen and easily mineralizable are an important source of energy accumulated in stable humic substances as well as of nutritional elements for plants and microorganisms. Thus, they contribute to the protection of stable humic substances from the impact of destruction-mineralization processes. At the same time, they are receptive to external impact, are prone to restoration and easily manageable.

Table 3. Energy potential of the organic matter system of chernozems in the area between the Prut and Dniester rivers under various conditions of layer maintenance (0-30 cm)

Maintenance mode	Energy potential structure: forms of energy						
	Total, gJ/ha	Inert		Potentially Active		Active	
		gJ/ha	%	gJ/ha	%	gJ/ha	%
Leached clayey loam chernozem							
Hayfield	6410	4731	73.8	994	15.5	685	10.7
Lightly overcultivated arable land	4020	3373	83.9	462	7.2	186	8.9
Moderately overcultivated arable land	3278	2888	88.1	200	6.1	190	5.8
Heavily overcultivated arable land	2650	2483	93.7	77	2.9	90	3.4
Typical moderately humus-rich clayey loam chernozem							
Forest strip	4715	3715	78.8	604	12.8	396	8.4
Fallow (16 years)	4352	3094	71.1	596	13.7	662	15.2
Lightly overcultivated arable land	2971	2757	92.8	42	1.4	172	5.3
Moderately overcultivated arable land	2487	2358	94.8	22	0.9	107	4.3
Heavily overcultivated arable land	1905	1833	96.2	13	0.7	59	3.1
Typical weak humus-rich clayey loam chernozem							
Hayfield	4771	3678	77.1	692	14.5	401	11.4
Lightly overcultivated arable land	3116	2674	85.8	207	6.6	235	7.6
Moderately overcultivated arable land	2422	2197	90.7	109	4.5	116	4.8
Heavily overcultivated arable land	2188	2022	92.4	92	4.2	74	3.4
Clayey carbonate chernozem							
Fallow	3924	3288	83.8	370	9.1	266	7.1
Weakly overcultivated arable land	2438	2167	88.9	10.8	4.3	163	6.8
Moderately overcultivated arable land	2083	1950	93.5	48	2.3	85	4.1
Heavily overcultivated arable land	1477	1408	95.3	16	1.1	5.3	3.6

Non-humified humic substances within the system of organic substances have two basic functions: 1) protective - by continuously providing the necessary nutrition and energy for the soil biota, it minimizes the mineralization processes of stable humic substances; 2) humus-reproductive - by directly participating in the humification processes. From the data presented in Tables 2 and 3, we find that the content of these two groups of substances undergoes a significant reduction in arable chernozems and as a result, a unidirectional trend of dehumification has been established in the latter.

As a result, a unidirectional trend of reduction of humus reserves and its fulvatization is established in arable chernozems (Table 4).

Table 4. Composition of the humic system of typical moderately humiferous chernozems (state 0-30 cm) under various maintenance conditions

Mode of maintenance	Carbon content % of total C											
	Total	Humic acids				Fulvic acids					C non-hydrolyzed residue, %	Cah/ Caf
		AH 1	AH2	AH3	Suma	AF1	AF2	AF3	AF4	Suma		
Forest strip (47 years)	2.68	11.8	27.5	3.9	43.2	1.9	6.7	15.2	2.8	26.5	30,3	1.63
Fallow land (16 years)	2.39	10.7	26.5	8.0	45.2	1.9	5.5	119	5.0	24.3	30.5	1.86
Lightly overcultivated arable land	1.98	14.0	19.7	6.2	39.9	6.6	7.9	10.0	4.8	29.3	30.8	1.37
Moderately overcultivated arable land	1.70	14.7	17.8	4.6	37.1	7.6	8.6	10.9	4.4	31.4	31.4	1.18
Heavily overcultivated arable land	1.32	14.9	18.1	4.6	37.6	7.8	8.8	9.8	4.9	31.3	31.1	1.21

From the data presented in Table 4, we find that in uncultivated soils (forest strip) the total organic carbon content (2.68%) is 0.70% higher than in soils with a low degree of overcultivation and 0.98% higher than in soils with a moderate degree of overcultivation. In soils with a high degree of overcultivation, the total organic carbon content is 1.36% lower than in uncultivated soils.

At the same time, the carbon content of the unhydrolyzed residue practically does not change. This allows us to conclude that the changes in the composition of the humus of arable chernozems are determined by the peculiarities of the agrogenetic pedogenesis process under conditions induced by the intercalated action of physical degradation and climate change (Khokhlova et al., 2014; Khokhlova et al., 2015).

The specified dehumification processes are not limited to the arable layer and extend to the AmBm and Bm transition horizons. At the same time, however, the processes of reproduction of humus reserves are mainly limited to the arable layer. In the underlying horizons, as a result of the reduction in the amount of bioenergy resources, insignificant amounts of humus are produced, which to a small extent compensate for the amounts of humus subjected to mineralization.

At the same time, the quantities of humic substances eluted from the arable layer to the underlying ones are significantly reduced.

As a result, in the lower horizons, compared to uncultivated soils, an uncompensated balance of humus is established.

In this sense, depending on the humus regime, the humiferous profile of arable chernozems is divided into two layers: a) arable with a quasi-balanced regime and balance of humus corresponding to the biohydrothermal and bioaerohydric conditions induced by the intercalated impact of agrogenesis and climate change: b) subarable - with an uncompensated-regressive balance as a result of humus mineralization. This implies the conclusion that under agrogenesis conditions the progressive-accumulative profile of native chernozems develops in a regressive-accumulative sense, and the trend of these changes is unidirectional with specific features depending on the soil subtype (Table 5).

Table 5. Elements of evolution of the humus profile of the chernozems of the area between the Prut and the Dniester in arable regime (native/arable)

Parameters	Chernozems				
	clay-iluvial	leachates	typical moderately humiferous	typical weakly humiferous	carbonate
Humus content in the 0-50 cm layer, %	4.23/3.75	5.04/4.06	4.90/3.98	3.60/2.65	2.88/2.41
Humus content in the 50-100 cm layer, %	2.26/2.29	2.40/2.10	2.17/2.17	1.52/1.06	1.39/1.35
Humus reserves, t/ha 0-50 cm	233/215	277/227	270/233	198/148	173/135
50-100 cm	124/143	144/131	130/136	91/66	76/71
0-100 cm	357/358	421/358	400/359	289/214	249/206
Evolutionary trend of the humus profile: compacted soil→arable soil	Accumulative with weak features of weak eluvial-iluvial differentiation → attenuation of the degree of eluvial-iluvial differentiation	Cumulative with weak features of progressive cumulative→uniform cumulative	Progressive-accumulative→more attenuated degree of progressive accumulation	Uniform accumulative with beginnings of regressive-accumulative→slightly regressive-accumulative features	Uniform accumulative with less quantitative expression→uniform accumulative with more expressed regressive-accumulative features

Despite the specified functional changes, the morphogenetic profile of arable chernozems retains the basic features inherited from the pre-agricultural stage. The unidirectional direction of the functional changes implies the conclusion of subsequent genetically determined transformations, over time, of the morphogenetic profile (Gromovic, 2024).

Elements of this are attested, by, at this stage and are manifested in the diversification of the basic features of the arable horizon (Table 6).

Table 6. Types of arable horizons characteristic of arable chernozems in the area between the Prut and Dniester rivers

Horizon, %	Humus content, %	Humus balance	Intensity of bioaccumulative processes	Degree of structuring	Aggregate stability
Agrocernic	› 6	Positive	High	Excellent	Excellent
Agromolic	5-6	Positive/balanced	Increased	Very good	Very good
Agrohumic	4-5	Balanced	High	Good	Good
Agroumbric	3-4	Unbalanced	Moderate/weak	Moderate	Moderate
Agro Greek	2-3	Severely unbalanced	Weak	Low	Low
Agrocenusius	‹ 2	Extremely negative	Very low	Very low	Very low

Based on the above, we consider that agrogenic evolution is genetically inevitable and its mitigation in order to preserve basic eco/agroecosystem functions and services requires differentiated management of soil bioenergetic resources (Almanova et al., 2023).

CONCLUSIONS

Along with the significant reduction in the total organic matter content in the soil, a stable trend of reducing the content of non-humified organic matter and mobile humic substances is also attested, and as a result, a unidirectional trend of dehumification has been established in the soils.

In the composition of the humic system, the total content of fulvic acids increases, and the Cah:Caf ratio presents values (< 1.4) that are not characteristic of the chernozems in the region.

The stable values of the hydrolyzed residue content imply the conclusion that the changes in the composition of the humic system of arable chernozems are determined by the peculiarities of pedogenesis under conditions of agrogenesis and climate change. The humiferous profile of arable chernozems is clearly divided into two layers and indicates the substitution of the progressive-accumulative humiferous profile with the regressive-accumulative one, and the trend of these changes is unidirectional with specific features depending on the soil subtype.

The relatively short period of use of chernozems in arable regime was sufficient for the establishment, in the upper segment of the pedogenetic profile, of an arable horizon with features significantly detached from the humus-accumulative one.

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