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LAWFUL ANATOMICAL TRANSFORMATION OF THE BASIC PHYSICAL PARAMETERS OF ARABLE CHERNOZEM LAND IN THE AREA BETWEEN THE PRUT AND NISTER RIVER

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Abstract

Through the perspective of the biophysical concept and the priority role of the interdetermined and interdependent processes of humus formation and accumulation, as well as aggregation-structuring in the realization of the chernozem process of solification, materialized in the pedofunctional system [bioenergetic system]↔[aggregate system], the basic physical parameters of chernozems are the indices of the structural-aggregate state. The changes in the composition and functioning of the humic system, induced by the inclusion of agricultural chernozems in the agricultural circuit, led to the establishment of an evolution trend of the aggregate system, indispensable and dependent on the tillage system. At the hierarchical level of the microaggregate, the evolution of the structural-aggregate indices is manifested by the increase in the content of microaggregates > 0.01 mm. At the hierarchical "aggregate" level, the evolution processes of the aggregate system materialize in the stable tendency of regeneration of the aggregation-structuring process and its intensification, as the degree of soil disturbance. At the same time, however, the 5-year period is insufficient to ensure a unidirectional trend of stabilization (hydrostabilization) of the aggregate structure, the main limiting factor being the insufficient humus content.

Key words*: physical parameters, soils, structural-functional, typogenetic, chernozem.*

INTRODUCTION

From the perspective of the concept of chernozem evolution under agroecosystem conditions, the meaning and intensity of chernozem typogenetic processes are determined by the physical state of the soil responsible for the pedogenetic and pedofunctional regimes of the soils (Jigău, 2023a; Jigău et al., 2023b).
Despite this fact, both in the agricultural systems practiced in the last century and at present, the physical properties of the soils have been and are still neglected, with the emphasis placed on mineral fertilization and soil tillage. At the same time, research in the field of soil physics has had a predominantly agronomic-utilitarian character through the relations in the "soil-plant" system, their management being reduced to the "optimization" of the physical state through soil tillage, despite the fact that multiple research in the field has shown that these and the effects induced by them play one of the main roles in modifying the physical properties of the soils and the pedogenetic and pedofunctional regimes determined by them (Canarache, 1990).
At the same time, more recent research has shown that none of the technologies practiced in contemporary agriculture provide the necessary conditions for a unidirectional regeneration of chernozem typogenetic processes and, respectively, the expanded reproduction of the chernozem pedogenetic process, although the so-called "conservative tillage systems" involve some pedoregenerative elements. In this concept, the present research involves the identification and evaluation of the evolution laws of the basic physical parameters under the conditions of various tillage systems in order to improve and optimize them in a pedoregenerative sense (Shaxson, 1998; Nortcliff, 1998; Karlen et al., 1997).

MATERIALS AND METHODS

The theoretical framework of the present research is provided by the Law of Ecological Determinism, according to which chernozem pedogenesis in the space between the Prut and the Dniester is the product of the interdependent and interdetermined evolution of the landscape and soil in its basic quality of the landscape and involves its examination only within the concrete landscape conditions. The methodological framework is provided by the Law of Genetic Determinism and involves the examination of chernozem pedogenesis only through the prism of its dependence, exclusively, on the granulometric composition (inherited from the parent rock) and the content and composition of the humic system of the soil (Jigău et al., 2022).

In this sense, from the perspective of the bio-physical concept of pedogenesis, it represents a complex of processes of integration of abiotic and biotic matter materialized in the modeling of the mineral component in accordance with the needs of the soil biota. Through this prism of ideas, namely, the physical properties of the mineral substrate are subjected to the highest degree of pedogenetic transformation by the soil biota, which implies the conclusion that chernozems represent a natural model of pedogenetic formation with an optimal structural-functional composition - a standard for modeling soil matter through the integration of biotic and abiotic matter and materialized in the physical state of the soil.

Through this prism of ideas, the physical state of the soil is the product of multiple interactions between the abiotic components (solid, liquid, gaseous) and the biotic one, which involve two interdependent and interacting stages: a) the formation of the physical system (soil system) through the interaction of the physical phases; b) the formation of the soil ecosystem (biophysical system) through biogenic modeling mechanisms of the physical system. This implies the conclusion that the basic physical parameters are to be evaluated in interdependent and interdetermined interactions within the biophysical system.

In this context, the present research involves: a) the identification of the basic physical parameters that characterize the physical state of the soil: b) the identification of the meaning of the intensity of the processes of modification of the basic physical parameters and the laws of their evolution.

The achievement of the proposed objectives involves the identification of integral functional parameters easily accessible for evaluation that reflect the soil reaction to intercalated inputs induced by agrogenesis and climate change manifested in the meaning and intensity of chernozem typogenetic processes (humus formation-accumulation; carbonate migration, soil mass aggregation-structuring).

In this sense, our previous research has shown that the basic integrating parameter of the meaning and intensity of chernozem typogenetic processes are the humus state and soil structure (Kuznetsova et al., 2011; Kholodova et al., 2019; Semenov et al., 2020).

In our research for the evaluation of the meaning and intensity of the processes of evolution of the structural-aggregate state, the structural-aggregate parameters were used as follows:

> 10 mm – the amount increases during plowing, their content indicates the degree of degradation of the structural-aggregate state. The higher the content of aggregates > 10 mm, the higher the degree of degradation of the structure;

10-2 mm – an increase in their amount indicates the realization of the processes of regeneration of the chernozem structure in soils; a decrease in their amount indicates the degradation of the structure;

2-1 mm – is characterized by relatively stable amounts during vegetation and indicates its compensatory reproduction;

1-0.25 mm – aggregate reserve – in conditions of regeneration of meso-and macroaggregates the amount of the fraction;

1-0.25 mm is reduced as a result of its consumption during the formation of aggregates;

1-10 mm an increase in its content indicates a low intensity of the realization of the processes of regeneration of the aggregate structure in soils;

< 0.25 mm – its quantity is reduced during plowing and increases when aggregate layers are regenerated.

Our more recent research has shown that under conditions of agrogenetic pedogenesis and soil humus deficiency in arable chernozems with coagulation, root and coprolitic aggregation-structuring processes, a specific compensatory-

mechanical mechanism is realized caused by the increase in the degree of contrast of thermal and hydrothermal regimes with the formation of aggregates > 5 mm. This process occurs more intensively in the middle and lower segments of the profile. In the upper segment under conditions of deficient humus content (< 3.5%), the increase in the content of aggregates > 5 mm is determined by mechanical processes induced by soil tillage.
For the reasons specified in our research, the mechanical processes of aggregate formation > 5 mm were united in a separate group of metastructuring processes and for their quantitative evaluation the ratio > 5 mm: < 5 mm is used. The higher the specified ratio, the more intensive the metastructuring process of the aggregate structure (Jigău et al., 2022).
Laboratory research included: determination of humus content - TINAO method; determination of the composition of the humic system - I. V. Tiurin method; determination of the structural-aggregate composition - Savviniv method (dry fractionation); and aggregate stability (fractionation in water) - Savvinov method.

RESULTS AND DISCUSSIONS

With reference to the current state of arable chernozems and their evolution through the prism of the Law of the priority role of the processes of formation-accumulation of humus and those of aggregation-structuring of soil matter, we consider that the current degradative trend of the chernozem process of solification is determined by the disruption of the interdependent and interdetermined functionality of the pedofunctional system [bioenergetic system]↔[aggregative system] under agrogenic conditions.
The primary factor with direct impact, which determines the disruption of the functionality of the pedofunctional system [bioenergetic system]↔[aggregative system] is the negative transformation of the structural-aggregative organization of chernozems which leads to quantitative and qualitative changes in the process of formation and accumulation of humus, as well as its localization in the restructured structural aggregates under conditions of agrogenic pressure (Jigău et al., 2022).
The degradation of the structural-functional organization of soil organic matter, materialized in the total loss of hydrostability by structural aggregates > 5 mm, leads to a significant modification of the process of humus formation-accumulation in structural aggregates and creates premises for the intensification of humus mineralization processes. As a result, the chernozems in the region are in the critical phase of bioenergetic degradation materialized in soil overcultivation (Table 1).

Table 1. Evolution of the composition of the bioenergetic system of typical moderately humiferous chernozems under conditions of agrogenic overcultivation

Maintenance mode	Total organic matter content	Composition of the bioenergetic system, % of total organic matter content		
		Humus	humified organic matter	Humic substances extracted in 0.1n NaOH
Forest strip (47 years)	5.84	78.8	12.8	8.4
Fallow land 16 years	5.39	76.1	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

The amount of non-humified organic matter is reduced in poorly cultivated chernozems by 9 times, in moderately overcultivated ones by 14 times, and in strongly overcultivated ones by 18 times. As a result, during the vegetation period, the amount of organic phytonutrients (extracted in 0.1n NaOH solution) formed in the process of decomposition of organic residues is reduced by 1.4 times in poorly overcultivated chernozems, by 1.9 times in moderately overcultivated ones, and by 2.7 times in strongly overcultivated ones.

Therefore, the degree of exposure of inert humus to mineralization processes significantly increases, which entails the disaggregation of the soil mass and the intensification of the humus mineralization process.

The biohydrothermal and bioaerohydric environment that was established in chernozems after their inclusion in the agricultural circuit led to changes in both the course of the humification process and the composition of their humic system (Table 2).

Table 2. Composition of the humic substance system of typical moderately humiferous chernozems under overcultivation conditions

Maintenance mode	Total C, %	C humic acids, %				C fulvic acids					C hydrolyzed residue, %	Cah/ Caf
		Ah 1	Ah2	Ah3	∑	Af1a	Af1	Af 2	Af3	∑		
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	11.9	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

The data in Table 2 show that in arable chernozems a pedogenetic environment was established that was much different from that characteristic of uncultivated soils, which led to the modification of both the course of the humification process and the composition of the humic system. In this sense, in the composition of the humic system, the content of the mobile humic acid fraction (Ah1) that forms compounds with monovalent cations (Na+K+) and mobile forms of R2O3 increased, as well as the Ah3 fraction that forms stable complex compounds with R2O3 and clay minerals.

Under the newly formed biohydrothermal conditions, the synthesis of “aggressive fractions” of fulvic acids (Af1a, Af1) proceeds more intensively. The total content of fulvic acids increased by about 1.2-1.3 times and the Cah:Caf ratio decreased to 1.37-1.18, values uncharacteristic of typical moderately humic chernozems. At the same time, the carbon content of the unhydrolyzed residue practically does not change. This allows us to consider that the changes in the composition of the humic system of arable chernozems are determined by the changes in the mechanisms of the humification process at the current stage of evolution of arable chernozems within the framework of anthropogenic-natural chernozem pedogenesis. At the same time, from the data presented in Tables 1 and 2, we note that the biohydrothermal and bioaerohydric environment with a lower degree of oxidation, induced by the substitution in the fallow regime of the pronounced non-percolative exudative-transpirative water regime (characteristic of overcultivated chernozems) with the non-percolative deductive-transpirative water regime (characteristic of overcultivated chernozems) contributed, over a short period of time (16 years), to the restoration of the total organic matter content up to about 92% compared to the forest strip (Table 1) and to the transformation of the "aggressive fractions" of humic substances (Ah1, Af1a, Af1) into more stable humic substances (Ah2, Ah3) (Table 2) which contribute to the regeneration of aggregation-structuring processes and the restoration of the aggregate system.

This implied the conclusion that the transfer of overcultivated soils into fallow is the only procedure that can lead to the restabilization of the chernozem process in them (Sharkov & Antipina, 2022).

At the same time, however, the cited authors mention that under the conditions of "market agriculture" this procedure can only be used on a small scale in areas where for certain reasons it is not appropriate to cultivate agricultural crops. At the same time, several authors argue that the technologies practiced in contemporary agriculture cannot ensure the reproduction of humus reserves to quantities corresponding to the bioclimatic potential of the region (Kerschen, 1992).

In this context, it is imperative to evaluate the humus formation-accumulation-stabilization potential of current agricultural technologies in order to manage the basic physical parameters responsible for reproducing the chernozem process of pedogenesis.

Our research during 2011-2015 in an experimental plot in the North Moldovan plain showed that "alternative" soil tillage systems have different potential for humus formation-storage-stabilization (Table 3).

Table 3. Composition of the humic system of typical moderately humiferous chernozem depending on the tillage system (average data 2011-2015) (layer 0-50 cm), % of total C

Humic components	Maintenance mode				
	Forest strip	Plowing	Chisel work	Shallow work	No-till
Total C, %	2.58	1.98	2.00	2.03	2.04
C mobile humic substances	8.76	4.46	7.02	9.12	10.36
C water-soluble humic substances	0.85	0.80	0.82	0.83	0.5
C humic acids	39.64	36.94	38.06	38.33	38.11
C fulvic acids	20.18	26.90	23.82	22.11	20.38
C strable humus	30.57	30.90	30.28	29.61	30.30
Cah:Caf	1.96	1.37	1.60	1.73	1.87

From the data presented in this report, we find that, compared to uncultivated soils, all evaluated technologies have a lower potential for humus formation-storage-stabilization. At the same time, the comparative analysis of the impact of plowing and alternative tillage systems (chisel tillage, shallow tillage (Mini-till with mulch), No-till) shows that the latter contribute to the regeneration of the humus formation-storage-stabilization process in the soil. An informative parameter in this regard is, first of all, the content of mobile humic substances, which exceeds in the case of shallow tillage by 1.04 times and in the case of No-till by 1.18 times their content in uncultivated soils (forest strips).

Compared to the plowing variant, their content is 2.04 times higher in the shallow tillage variant and 2.32 times higher in the No-till variant.

In the case of the chisel tillage system, the content of mobile humic substances is lower than in uncultivated soils but is 1.57 times higher than in the plowing variant.

Under conditions of “alternative systems” of soil cultivation, the humification process proceeds with the formation, predominantly of humic acids. As a result, the Cah: Caf ratio increases from 1.37, the plowing variant, to 1.60 (chisel cultivation), 1.73 (shallow cultivation) and 1.87 (No-till).

The specified values allow us to consider that within the “alternative systems” of soil cultivation, a different biohydrothermal and bioaerohydric environment is created for the humification process. At the same time, the practically identical values of the content of non-hydrolyzed residue allow us to consider that the changes attested in the composition of the humic system are determined, exclusively, by the environment induced by the cultivation systems.

Based on the above, we can conclude that the bioenergetic system of overcultivated arable chernozems is receptive to agrotechnological measures for its restoration.

At the same time, however, to ensure the stability of this trend and more efficient realization of the biopedoclimatic and agrotechnology potential, agrobiotechnological measures adapted to the specific landscape conditions are necessary.

Changes in the composition and functioning of the bioenergetic system of soils entail changes in the composition and functioning of the aggregate system.

Table 4. Microaggregate composition of typical moderately humiferous chernozem under various tillage systems (average data 2011-2015)

Tillage system	Depth, cm	Aggregate diameter, mm. Microaggregate content, %							
		1-0.25	0.25-0.05	0.05-0.01	0.01-0.005	0.005-0.001	< 0.001	> 0.01	< 0.01
Ploughing	0-50	2.5	36.4	51.3	5.6	2.6	1.6	90.2	9.8
Chisel tillage	0-50	3.9	36.1	50.8	5.3	2.5	1.7	90.5	9.5
Mini-till with mulch	0-50	4.1	33.0	54.3	5.4	2.4	1.6	90.5	9.5
No-till	0-50	4.8	33.2	54.3	4.8	1.9	1.0	92.3	7.7

At the hierarchical level "microaggregate" these are manifested in the increase in the content of microaggregates > 0.25 and 0.05-0.01 mm. The increase in the content of microaggregates > 0.25 mm is achieved at the expense of those with a diameter of 0.005-0.001 and < 0.001 mm. This allows us to consider that the microaggregation of the soil mass is supported by the modifications in the humification process specified above. The intensity of the microaggregation process increases in the order: chisel work → work → superficial → No-till, similar to the increase in the share of humic acids in the composition of the humic system (Table 5).

Table 5. Structural-aggregate composition of the agrogenic layer of typical moderately humitic chernozems in various tillage systems (average data 2011-2015), layer (0-50 cm)

Tillage system	Depth, cm	Aggregate diameter, mm. Microaggregate content, %						Structuring coefficient
		> 10	10-0.25	10-1	3-1	1-0.25	< 0.25	
Ploughing	0-50	26.8	71.1	62.0	51.2	11.4	2.1	2.5
Chisel tillage	0-50	20.3	77.4	65.0	54.0	10.9	2.5	3.4
Mini-till with mulch	0-50	16.2	81.6	66.8	55.2	11.6	2.4	4.4
No-till	0-50	14.8	81.9	67.0	56.2	10.6	1.7	4.5

In the hierarchical "aggregate" nickel, the evolution processes of the aggregate system materialize in the stable tendency of regeneration of the aggregation-structuring process within which a series of laws are achieved:

- reduction of the content of aggregates > 10 mm;
- increase to excellent values of the content of agronomically valuable aggregates (0.25-10 mm);
- increase of the content of 10-1 mm aggregates responsible for the pedofunctional regimes (hydrothermal, aerohydric, oxidation-reduction, biological);
- increase of the content of chernozem aggregates (3-1 mm) responsible for the hydrophysical properties of the soils;

In all the evaluated variants, the decisive role in the formation of the agronomically valuable structure belongs to the 10-1 and 3-1 mm aggregates. At the same time, however, the content of 10-1 mm aggregates under chisel work conditions in the 0-50 cm layer is higher than under plowing by 3%, and in the superficial and No-till variants by 4.8% and, respectively, 5%. The same pattern is achieved in the case of the 3-1 mm aggregate content, which compared to plowing is higher by 2.8%, 4.0% and, respectively, 5%. Both in the case of the 10-1 and 3-1 mm aggregate content, the aggregate profile of the agrogenic layer is divided into two substrates with different intensity of their formation mechanisms. The "ploughing" variant is characterized by the maximum degree of stratification of the agrogenic layer. In the case of the "shallow tillage" and "No-till" variants, the degree of stratification is insignificant and implies the conclusion that homogeneous conditions for the functioning of the biophysical system are created throughout the entire thickness, which indicates the regeneration of the aggregation-structuring process to the same extent.

The structuring coefficient decreases in the order No-till > shallow tillage > chisel tillage > plowing.

The evaluated technological systems differ significantly in their impact on the degree of aggregate stability. The total content of hydrostable aggregates increases in the following order: chisel tillage > No-till > plowing > shallow tillage (Table 6).

Table 6. Aggregate stability of the agrogenic layer of typical moderately humus-rich chernozems under various working conditions (average data 2011-2015)

Tillage system	Depth, cm	Aggregate diameter, mm. Microaggregate content, %						Hydrostability criterion, %
		5-3	3-2	2-1	1-0.5	0.5-0.25	<0.25	
Ploughing	0-50	-	2.4	16.9	17.2	31.7	33.4	429
Chisel tillage	0-50	-	4.7	20.4	16.6	31.4	25.8	440
Mini-till with mulch	0-50	-	3.2	19.3	16.1	26.4	33.7	366
No-till	0-50	-	9.4	30.8	12.7	13.8	30.2	250

At the same time, in the plowing, chiseling and shallow tillage variants, the major share in the composition of hydrostable aggregates belongs to the 1-0.25 mm aggregates, the content of which is, respectively, 48.9%, 48.0% and 42.4%. In the No-till variant, their content is 31.5%, and the content of hydrostable aggregates >1 mm is 44.1%, which is about 2.3 times higher than in plowing, 1.8 times higher than in chiseling and 2 times higher than in shallow tillage.

In the composition of hydrostable aggregates > 1 mm, the major share belongs to the 2-1 mm aggregates. Their average content in the 0-50 mm layer decreases in the order: No-till (30.8%) > chiseling (20.4%) > shallow tillage (19.3%) > plowing (16.9%). An analogous regularity is also observed in the case of 3-2 mm hydrostable aggregates: No-till (9.4%) > chisel work (4.7%) > shallow work (3.2%) > plowing (2.4%). At the same time, in the order plowing < chisel work < shallow work < No-till, a stable trend of increasing hydrostability of 5-3 mm aggregates is outlined.

The quantitatively mentioned regularities are correlated with the quantitative regularities, induced by the evaluated work systems, in the content and composition of the bioenergetics system, which allows us to consider that the increase in the hydrostability of structural aggregates is supported by the positive quantitative and qualitative changes occurring in the composition of the bioenergetics system and, respectively, in the interdependent and interdetermined functioning of the pedofunctional system [bioenergetics system]↔[aggregate system].

At the same time, however, the quantitative and qualitative parameters of aggregate stability imply the conclusion that the period of 5-7 years is insufficient to ensure a unidirectional trend of stabilization of the aggregate structure, and the main factor with limiting impact is the small amount of humus produced following the transformation-humification of organic residues produced by cultivated agrophytocenoses.

Another limiting factor is the advanced degree of physical degradation of the agrogenic layer, which ensures an internal pedogenetic environment that is less favorable for promoting the humification process but more favorable for the mineralization of soil organic matter, including newly formed humic substances.

CONCLUSIONS

From the perspective of the biophysical concept of the chernozem pedogenesis process, further indications for evaluating the meaning and intensity of chernozem typogenetic processes under agrogenesis conditions are the parameters of the structural-aggregate state, materialized in the interdetermined and interdependent interaction of the pedofunctional system [bioenergetic system]↔[aggregate system].

Their application has highlighted the basic laws of interdependent and interdetermined evolution of the process of humus formation-accumulation and that of soil mass aggregation-structuring within various tillage systems.

Under plowing conditions in arable chernozems, a stable tendency of overcultivation is established, manifested in the interdependent and interdetermined degradation of the basic chernozem processes.

Within the framework of technologies with conservative elements of soil cultivation, with a lower degree of disturbance, in arable chernozems a stable tendency of regeneration of chernozem typogenetic processes is established, their intensity being increasing as the degree of disturbance is reduced. Their intensity, however, depends on the quantities of newly formed humus. This implies the conclusion that the management of chernozem pedoregenerative processes must be based on the sustainability of bioenergetic resources and the reduction of mechanical pressures on them.

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