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AGRO-CLIMATOGENIC NEOHYDROMORPHISM: PLACE IN THE EVOLUTION OF ARABLE CHERNOZEMS

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Abstract

The evolution of chernozems within the current phase of anthropo-natural pedogenesis is influenced by the agro-climatogenic neohydromorphism whose development is determined by the modification of the atmospheric precipitation regime caused by climate change and the physical degradation of soils induced by agrogenesis. The latter manifests itself in the reduction of water permeability, the hydraulic conductivity of soils and the overwetting of their upper and middle segments during periods of heavy rainfall. As a result, within the space with an advanced degree of physical degradation, the automorphic-non-percolative hydric regime is replaced by the stagnant-non-percolative hydric regime (ephemeral, periodic, permanent) and the derno-chernosiomic pedogenesis is replaced by the hydrometamorphic one. Within it, the evolution of soils is determined by the processes induced by overwetting: gleyzation, montmorillonitization, metastructuring.

Key words: *non-percolating stagnant water regime, gleyzation, montmorillonitization, structure degradation, differential porosity.*

INTRODUCTION

The genesis of chernozems in the Pridanubian area is the product of typogenetic processes (formation and accumulation of humus, migration of carbonates, aggregation-structuring of the soil mass, biogenic accumulation) determined by the evolution and dynamics on the pedological scale of time, climate and other pedogenetic factors (biological, geomorphological) determined directly from this. As a result, the chernozems in the region have a high capacity to buffer the impact of various natural and anthropogenic factors, to adapt to the newly formed conditions and to preserve the characteristics and regimes of the soils, thus ensuring the stability and reproduction of the steppe landscapes. The substitution of the latter with agro-landscapes attracted significant changes in the pedogenesis of chernozems that led to the destabilization of agro-landscapes and the disturbance of the balance between their components established on the pedological scale of time. This led to the establishment in soils of a complex of interdetermined and interdependent processes and reactions materialized in the neohydromorphization of automorphic soils. The development of neohydromorphism gained momentum at the beginning of the seventies of the last century, the surface of neohydromorphized soils increasing from 30 thousand ha in 1972 to 50 thousand ha in 1980, 80 thousand ha at the end of the nineties, 120 thousand ha at the beginning of the current century. According to more recent calculations, their surface in 2020 was about 180 thousand ha. In our opinion, the development of neohydromorphism overlapped, over time, with the intensification of the processes of physical soil degradation and the differentiation of the soil profile into two distinct functional layers: a) agrogenic and b) underagrogenic.

Previous research on this subject was limited to: a) establishing the phenomenon; b) recording, through the lens of fertility factors, the quantitative and qualitative changes in soil characteristics and regimes; c) establishing the place in the classification system; d) development of procedures and measures for improvement and utilization. The genetic aspects were reduced only to the stagnation of water on the surface of the impermeable clay layer for water (Сувак, 1977; 1986).

In this paper, the neohydromorphism of chernozems is examined through the prism of the unity of the pedogenetic process within the genetic-evolutionary chain "factors ↔ regimes ↔ processes ↔ properties ↔ soil" taking into account the place of the soil in the evolution of pedogenetic factors. Through this prism of ideas, the soil cover is considered a factor with a decisive role in the current climate trend on a global and regional scale.

MATERIALS AND METHODS

In the framework of the working concept for evaluating the genesis of neohydromorphism, we start from the principle of the priority role of the degradation of physical properties and regimes in determining the meaning and intensity of cernoziomic typogenetic processes within the current phase of anthropo-natural cernoziomic pedogenesis. The disaggregation-destructuring of the chernozemic structure (3-1 mm), the reduction of aggregate stability, the overcompaction of the arable and sub-arable layer, the degradation of the pore space led to the reduction of water permeability and hydraulic conductivity, thus creating premises for the stagnation of water from atmospheric precipitation in the agrogenic layer of arable chernozems. At the same time, against the background of an increase in the average amount of precipitation by 8% in the cold semester and a reduction by 2.5% in the warm semester of the years 1991-2020 compared to 1961-1990, their seasonal regime changed in the sense of increasing the amount in the autumn months and decreasing in the summer months.

According to the data of the State Hydrometeorological Service, in about 40% of the years, in some periods of the year, the amount of atmospheric precipitation can exceed the amount of precipitation during the cold period of the year (1.XI-1.IV).

Against the background of the general decrease in the number of days with precipitation ≥0.1 mm, the frequency of the number of days with extremely abundant precipitation ≥50 mm has increased greatly.

The number of days with precipitation >20 mm is increasing by 11.7%, those with precipitation >30 mm by 27.4% and those with precipitation >50 mm is increasing by 132%.

In addition, in some years the deviation of the amount of precipitation from the multiannual average value can constitute ± 200-300 mm. In about 40% of the years, the deviation from the multiannual norm is ± 100 mm.

In conditions of an advanced degree of physical degradation in years/periods with abundant atmospheric precipitation, water stagnates in the upper and middle segment of the soil profile and the processes induced by overwetting start.

According to our more recent research, two distinct types are clearly outlined within the neohydromorphization process (Jigău et al., 2017).

The development of the first type is determined by the increase in the degree of continentality of the climate materialized in regional manifestations of humidification and aridification of soils that determine the imbalance of relations between the components of agro-landscapes and their degradation. In this sense, we consider that neohydromorphism is a response reaction of chernozems to the cumulative impact of the entire complex of anthropo-natural factors and one of the main causes that favors it is physical degradation. In this sense, research has shown that in years with abundant spring precipitation (2017), gravity water drains from the soil profile only in the second half of June.

In such years, the state of overwetting in the active pedogenetic layer of arable chernozems is maintained for a long period of time (April-June) (Jigău et al., 2017).

The second type of neohydromorphism is caused by the cumulative effect of humidification of the water regime of arable chernozems under conditions of agrophytocenoses as a result of the change in the mode of water consumption from the soil to evapo-transpiration.

The phenological rhythm of operation and the particularities of the root system of cultivated plants cause the reduction of water consumption from the lower horizons of the soil profile. The shorter the vegetation period of agrophytocenoses compared to biocenoses also contributes to this. At the same time, in arable chernozems, the porous space is divided into two substrates, with the formation of an anisotropic-discontinuous space. Therefore, during vegetation, water reserves from the agrogenic layer are consumed more intensively, including physical evaporation. As a result, there is a slow cumulative increase of water reserves in the lower horizons with the start of the processes of loosening the structural aggregates and clogging the pores, creating a predominantly reducing aerohydric regime.

In these conditions, the processes of quasi-gleyzation and local gleyzation start in the soils with the subsequent intensification of the phenomenon of changing the way of placement and packing of the solid components, and as a result, of the ratio between the mass and the volume of the soil phases in favor of the solid phase materialized in increasing the degree of compaction and reduction of the volume of the porous space.

Therefore, over time, the thickness of the layer available for wetting is reduced, so that even in the years with the amount of precipitation corresponding to the multiannual average, in the early phases of the vegetation period, in soils with an advanced degree of physical degradation, there is an excess of moisture, which implies a change in the meaning and the intensity of the chernozemic typogenetic processes and favors the hydrometamorphization processes (Jigău et al., 2017).

Starting from the working concept, the research included the evaluation of the changes in typogetic processes within a “chain” of soils with different degrees of development of neohydromorphism. The research involved applications in the field and in the laboratory. In the field were studied 6 soil profiles that characterize soils with different degrees of physical degradation and hydrometamorphism. Within the evaluated chain of soils the degree of physical degradation and hydrometamorphism increases as follows: typical chernozem with low humus content (forest strip) → typical chernozem with low humus content (arable land) → typical cvasi-gleyied chernozemlike soil with low humus content (arable land) → typical gleyied chernozemlike soil with low humus content → typical compacted chernozemlike soil with low humus content → gleyied hardsetted chernozemlike soil with low humus content. In order to evaluate the quantitative changes in the evolution processes of the mineralogical component, the mineralogical composition of the fine clay fraction was evaluated with the X-ray diffraction method (the analyzes were carried out in the Institute of Geology and Seismology, Chisinau). The humus composition was evaluated with the Kononova-Belicikova method (Kaurichev, 1980). The structural-aggregate composition was evaluated with the Savvinov method. The differential porosity was evaluated based on the suction curve (Jigău & Nagacevschi, 2006).

RESULTS AND DISCUSSIONS

The agro-climatogenic neohydromorphization of chernozems involves several genetic-evolutionary stages: a) seasonal - substitution of the non-percolating automorphic water regime with the stagnant-non-percolative ephemeral water regime; b) transitional - the establishment in soils of the periodic stagnant-non-percolative water regime; c) the development and deepening of the permanent stagnant-non-percolative water regime. Within the mentioned genetic-evolutionary stages, the derno-chernozemic pedogenesis is replaced by the hydrometamorphic pedogenesis, which involves the modification of the composition of all soil phases, including the living one, and materializes in the modification of the direction and intensity of the humus formation and accumulation process, the montmorillonitization of the finely dispersed fraction, the metastructuring of the soil mass, the restructuring of the porous space (Jigău et al., 2017; Jigău & Leşanu, 2021).

The evolution of the mineralogical composition of the fine clay fraction (<0.001 mm) under conditions of neohydromorphism is determined by its montmorillonitization as a result of illite-hydromicas (Table 1).

The data presented in Table 1 shows that the mineralogical composition of the <0.001 mm fraction of the automorphic chernozems, within the investigated chain, is characterized by illite-montmorillonite composition and relatively uniform distribution of illite and montmorillonite on the profile. Changing the water regime, already in the initial phase, leads to the start of the montmorillonitization process and the increase of the montmorillonite content up to 25.1%. With the increase in the degree of hydrometamorphism, the intensity of the montmorillonitization process intensifies with the formation of compacted gleyied and hardsetted gleyied profiles.

Table 1. The mineralogical composition of the fine clay fraction (<0.001 mm) of soils with different degrees of hydrometamorphism

Soil	Depth, cm	Mineral content, %				Finely dispersed quartz
		Montmorillonite	Illite	Chlorite	Kaolinite	
Typical chernozem with low humus content (forest strip)	0-10	40.8	44.3	5.9	9.0	13.9
	20-30	44.3	40.0	5.3	10.4	
	40-50	43.8	45.5	4.5	6.2	
Typical cvasi-gleyied chernozemlike soil with low humus content (arable land)	0-10	40.8	44.3	5.3	9.6	13.9
	20-30	44.3	40.8	8.5	6.4	6.9
	40-50	59.6	25.1	10.9	4.4	7.6
Typical gleyied chernozemlike soil with low humus content	0-10	37.2	45.6	9.8	7.4	17.8
	20-30	55.4	29.7	7.9	7.0	6.9
	40-50	73.9	15.3	4.5	6.3	5.3
Typical compacted gleyied chernozemlike soil with low humus content	0-10	44.3	46.1	6.9	2.7	12.2
	20-30	62.7	25.0	7.3	10.0	10.1
	40-50	72.4	17.5	6.1	4.0	10.1
Gleyied hardsetted chernozemlike soil with low humus content	0-10	37.8	45.3	8.4	8.5	18.7
	20-30	69.7	18.4	8.8	3.1	16.1
	40-50	69.3	19.9	6.4	2.3	7.6

Increasing the degree of hydrometamorphism leads to increasing the share of the humification process and reducing the share of the mineralization process within the decomposition-transformation process of organic matter in the soil, manifested in the increase of the organic carbon content. At the same time, however, as the hydrometamorphization process intensifies, the active humifer profile of the soils is clearly divided into two layers with different organic carbon content. The 0-30 cm layer in which the row organic matter is mainly stored is characterized by a unidirectional trend of increasing the organic carbon content. In the 30-50 cm layer, the organic carbon content remains practically unchanged. At the same time, the distribution of the fraction of mobile humic substances (extracted with 0.1 NaOH solution) in the active humic layer of chernozemlike soils indicates a more intensive humification process in the 0-30 cm layer.

The process of humification under conditions of neohydromorphism proceeds with the formation, predominantly of humic acids, and is manifested in the increase of Cha: Cfa values in the 0-30 cm layer of chernozemlike soils (Table 2). The changes that can be seen in the content and profile distribution of the carbon of the non-hydrolyzed residue allow us to consider that the particularities of the humic system of the studied soils are determined by the hydrometamorphism of the pedogenetic process.

The changes in the mineralogical composition of the fine clay fraction and in the composition of the humic system of the soils led to the establishment of the metaaggregation process in the chernozimoid soils, which led to a significant change in the structural-aggregate composition of the chernozemlike soils (Table 3).

This implies the increase, in chernozemlike soils compared to chernozems, of the content of aggregates >10 mm and the reduction by 10-15% of the content of agronomically valuable aggregates (10-0.25 mm).

Table 2. The composition of the humic system
of chernozemlike soils with different degrees of hydrometamorphism

Soil	Depth, cm	Carbon content, %	The composition of the humic system, % of the total C content				Cha/ Cfa
			C extracted with 0.1 NaOH	Cha	Cfa	C unhydrolyzed residue	
Typical chernozem with low humus content (forest strip)	0-10	2.86	5.8	36.1	18.9	39.2	1.91
	10-20	2.93	6.7	37.6	18.8	36.9	2.00
	20-30	2.32	7.7	34.4	19.7	38.2	1.75
	30-40	1.98	7.3	33.8	21.1	38.8	1.60
	40-50	1.72	6.1	33.1	21.9	38.4	1.51
Typical chernozem with low humus content (arable land)	0-10	2.31	9.6	31.7	20.6	38.1	1.54
	10-20	2.16	9.3	34.2	19.1	37.4	1.79
	20-30	1.87	8.4	35.8	20.3	35.0	1.76
	30-40	1.71	5.8	32.4	21.5	40.3	1.51
	40-50	1.67	4.7	32.7	22.1	40.5	1.47
Typical cvasi-gleyied chernozemlike soil with low humus content (arable land)	0-10	2.77	10.2	34.9	18.9	36.0	1.85
	10-20	2.42	10.0	36.2	18.9	34.9	1.92
	20-30	1.90	7.1	33.2	19.4	40.3	1.71
	30-40	1.74	5.4	33.8	20.7	40.1	1.63
	40-50	1.65	4.8	32.6	21.1	41.5	1.55
Typical gleyied chernozemlike soil with low humus content	0-10	2.81	11.8	38.2	19.1	30.9	2.00
	10-20	2.63	11.3	37.7	19.4	31.6	1.94
	20-30	2.55	10.0	35.5	20.3	34.2	1.75
	30-40	1.83	7.9	33.8	20.9	37.4	1.62
	40-50	1.66	7.7	31.5	21.7	39.1	1.45
Typical compacted gleyied chernozemlike soil with low humus content	0-10	2.91	11.5	39.1	19.8	29.6	1.97
	10-20	2.71	10.7	38.3	20.3	30.7	1.89
	20-30	2.27	6.3	36.8	20.9	36.0	1.76
	30-40	1.76	5.1	34.0	21.6	39.3	1.57
	40-50	1.58	4.1	33.1	21.8	41.0	1.52
Gleyied hardsetted chernozemlike soil	0-10	2.86	11.7	38.9	19.4	30.0	2.01
	10-20	2.67	11.0	37.9	19.9	31.2	1.90
	20-30	2.44	9.9	36.2	20.3	33.6	1.78
	30-40	1.80	5.3	33.7	20.9	40.1	1.61
	40-50	1.60	4.4	31.4	21.7	42.7	1.45

The content of 5-1 mm aggregates and waterstable aggregates undergo less noticeable changes.

In our opinion, the "relative conservation" of the chernozems structure (5-1 mm) and its waterstability is due to the permanent reproduction of aggregates <5 mm with the participation of newly formed humic substances, the aggregation process being supported by the predominance of calcium cation (Ca^{2+}) in the composition of the adsorptive complex of chernozemlike soils (Jigău & Leşanu, 2021).

The changes in the structural-functional organization of chernozemlike soils led to the restructuring of their porous space. From Table 4 we can see that as the degree of hydrometamorphism intensifies, the total pore volume decreases significantly from 62-63% to 47-52% in the 0-30 cm layer and from 61-62% to 43-45% in the 30-50 cm layer.

The specified changes are made on account of interaggregate pores (aeration pores) whose volume is much (about 1.3-2 times) below the limit of critical values. As the soil mass is reorganized in the compact and slitted chernozemlike soils, a slight reduction in the capillary pore volume can also be seen. The changes in the composition of the porous space allow us to consider that the agro-climatogenic neophydromorphism established in chernozems with an advanced degree of physical degradation has an irreversible unidirectional character.

Table 3. Aggregate structural composition of chernozem soils with different degree of hydrometamorphism

Soil	Depth, cm	Aggregate size, mm Content of aggregates, %				Waterstable aggregates
		>10	Σ10-0.25	5-1	<0.25	
Typical chernozem with low humus content (forest strip)	0-10	9.6	87.2	57.4	3.2	50.5
	10-20	10.9	85.9	59.8	3.2	49.8
	20-30	11.3	85.8	61.3	2.9	48.8
	30-40	12.8	84.5	57.9	2.7	48.2
	40-50	13.4	83.9	56.6	2.7	47.8
Typical chernozem with low humus content (arable land)	0-10	16.9	80.2	52.1	3.9	46.5
	10-20	16.7	79.5	53.6	3.8	49.7
	20-30	19.9	77.0	53.2	3.1	47.7
	30-40	13.3	83.8	54.7	2.9	51.3
	40-50	13.8	83.3	52.0	2.9	50.8
Typical cvasi-gleyied chernozemlike soil with low humus content (arable land)	0-10	24.6	71.6	50.7	3.8	46.5
	10-20	28.9	68.6	48.4	2.5	49.6
	20-30	36.2	62.0	48.4	1.8	48.6
	30-40	29.6	68.6	49.1	1.8	49.4
	40-50	28.4	69.9	48.9	1.7	48.9
Typical gleyied chernozemlike soil with low humus content	0-10	26.1	69.7	52.5	4.2	47.4
	10-20	28.4	68.3	49.8	3.3	47.8
	20-30	38.9	59.7	51.6	1.4	50.3
	30-40	32.7	65.6	49.0	1.6	46.1
	40-50	32.0	66.9	48.3	1.1	48.4
Typical compacted gleyied chernozemlike soil with low humus content	0-10	26.3	69.2	53.6	4.5	49.8
	10-20	31.1	67.0	46.3	2.9	49.6
	20-30	39.1	59.1	43.2	1.0	48.3
	30-40	39.8	59.4	41.6	0.8	49.8
	40-50	35.3	63.5	44.9	1.2	45.7
Gleyied hardsetted chernozemlike soil with low humus content	0-10	30.7	67.4	48.5	1.9	50.2
	10-20	32.5	66.2	46.7	1.3	47.7
	20-30	36.9	62.4	43.1	0.8	44.9
	30-40	39.1	59.9	35.9	1.0	40.7
	40-50	38.0	61.0	36.6	1.0	39.6

Table 4. The differential porosity of chernozemic soils with different degrees of hydrometamorphism

Soil	Depth, cm	Porosity, (Ɛ), %					
		Ɛt	Ɛw	Ɛase	Ɛall	Ɛk	Ɛaer
Typical chernozem with low humus content (forest strip)	0-10	62.5	31.4	8.7	5.1	17.6	31.1
	10-20	62.7	34.8	8.4	5.4	21.0	27.9
	20-30	62.3	33.6	8.4	5.6	19.6	28.7
	30-40	61.6	30.4	8.1	5.5	16.8	31.2
	40-50	58.3	29.9	8.3	5.7	15.9	28.4
Typical chernozem with low humus content (arable land)	0-10	57.8	33.7	8.5	5.3	19.9	24.1
	10-20	56.1	35.3	8.9	5.5	20.9	20.8
	20-30	54.8	36.0	9.1	5.7	21.2	18.8
	30-40	53.5	36.4	9.3	5.7	21.4	17.1
	40-50	52.7	38.3	9.8	5.9	22.6	14.4
Typical cvasi-gleyied chernozemlike soil with low humus content (arable land)	0-10	55.3	44.0	9.1	5.6	29.3	11.3
	10-20	55.3	44.3	9.0	5.4	29.9	11.5
	20-30	53.7	42.8	9.4	5.6	27.8	10.9
	30-40	52.1	43.2	9.7	6.0	27.5	8.9
	40-50	50.9	44.8	10.4	6.2	28.2	6.1
Typical gleyied chernozemlike soil with low humus content	0-10	52.7	44.3	9.3	6.3	28.7	8.4
	10-20	53.4	44.8	9.3	6.4	29.1	8.6
	20-30	51.2	43.0	9.8	6.0	26.2	8.2
	30-40	49.7	42.2	9.8	5.9	26.5	7.5
	40-50	49.3	42.0	10.1	5.9	26.0	7.3
Typical compacted gleyied chernozemlike soil with low humus content	0-10	51.8	43.7	9.2	6.0	28.5	8.6
	10-20	49.4	42.0	9.4	5.7	26.9	7.4
	20-30	47.8	41.6	9.6	5.7	26.3	6.2
	30-40	45.3	40.8	9.6	5.4	25.8	5.3
	40-50	45.9	40.9	9.4	5.9	25.6	5.0
Gleyied hardsetted chernozemlike soil with low humus content	0-10	50.1	41.9	9.3	5.7	25.9	8.2
	10-20	47.3	40.2	9.3	5.7	24.2	7.1
	20-30	45.0	40.0	9.6	5.4	25.0	5.0
	30-40	43.7	38.2	9.6	5.4	22.2	5.5
	40-50	43.4	38.8	9.8	5.3	23.7	4.6

CONCLUSIONS

The development of agro-climatogenic neophydromorphism is favored by changes in the atmospheric precipitation regime induced by the current trend of regional climate conditions and by the advanced degree of physical degradation of arable chernozems. Within it, the derno-chernosiomic pedogenesis process is replaced by the hydrometamorphic pedogenesis process materialized in the montmorillonitization of the mineralogical composition of the fine clay, the intensification of the humification process with the predominant formation of humic substances and the metaaggregation of the soil mass with the formation of aggregates >10 mm. The evolution of the volume and structure of the porous space indicates that the processes induced by neohydromorphism are unidirectional and irreversible, materialized in a new form of chernozems degradation - the hydrological one.

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