

THE SUSTAINABLE MANAGEMENT OF THE PROCESSES OF SEQUESTRATION AND STABILIZATION OF THE ORGANIC CARBON IN CHERNOZEMS BY THEIR AGGREGATION-STRUCTURING

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ABSTRACT

The process of pedogenesis involves the development and synchronized and interdetermined evolution of the processes of formation-accumulation of humus and those of aggregation-structuring. Their interdetermined interaction materializes in the constitution of the system of organic substances, the humic profile and the aggregate system / aggregate profile of the soil. Within the pedogenetic profile, the humeral and the aggregate profile overlap quantitatively and qualitatively, being interdetermined.

Sequestration-stabilization of organic carbon in soils is the product of the concomitant realization of physico-chemical, chemical and biophysical mechanisms of structural organization of soil mass with the formation of pedogenetic formations characteristic only to soils whose basic function is sequestration-stabilization of organic carbon in soil.

Under agroecosystem conditions, the carbon-sequestration potential of chernozems is reduced due to the quantitative and qualitative changes induced by agrogenesis. This involves only partially achieving the organic carbon sequestration function. In addition, agricultural works lead to the degradation of the structure, the intensification of humus mineralization processes and the increase of C-CO₂ emissions from the soil to the atmosphere.

Algalization contributes to the aggregation of soil mass structure even in the first year after administration. Newly formed aggregates have loose organization and reduced hydrostability.

In order to increase the degree of compaction-consolidation of the newly formed aggregates, it is recommended to cultivate multiannual grasses and administer once in 4-5 years 5 t / ha of amendments with calcium-waste from the sugar industry and the thermal energy branch.

Key words: management, processes, organic carbon, chernozems

Introduction

Inventory of sources, identification of leaks and quantitative release of carbon fluxes into the atmosphere is one of the basic conditions for the development of long-term strategies and tactics aimed at mitigating climate change.

The global balance of carbon dioxide in the atmosphere is determined by the volumes of its emissions from natural and anthropogenic sources.

Soils are the main "warehouse" of carbon in the biosphere. The global content of organic carbon in the soil 4 times exceeds the content of biotic carbon and about 3 times that of the atmosphere.

The humusosphere of soil resources accounts for 2/3 of the total organic carbon content in terrestrial ecosystems.

The average lifespan of carbon in the atmosphere is 5 years, in plant biomass 10 years, and in soils 35 years. Thus, soils not only store organic carbon but preserve it for a longer period of time. According to calculations, some fractions of humus have a lifespan expressed in thousands of years.

Soils also play a major role in the transfer of carbon from the atmosphere to the lithosphere through the process of photosynthesis. In this sense, one of the basic ecosystem functions of soils is the storage of both plant and animal organic residues, their biochemical decomposition-transformation with the formation of humus, a specific organic substance characteristic only of pedogenesis.

Carbon transfer from the atmosphere to plant biomass, decomposition, transformation and humification of organic dead soil, humus formation and conservation of organic carbon for a long time with minimal risk of return to the atmosphere is the global process of "sequestration of carbon in the soil".

Quantitative carbon sequestration in soil is assessed based on sequestration potential and soil / ecosystem sequestration capacity.

The sequestration potential of soils / ecosystems characterizes the intensity of carbon flow in soils with organic residues and fertilizers. It is 0.4-1.2 G / year. (Lal R., 2004).

The ability to sequester carbon in the soil reflects its feature of stabilizing and conserving in

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the composition of humus the carbon contributed to the soil with organic matter (organic waste and fertilizers).

Z.S. Artemieva and N.P. Chirilova (2017) find that the ability to sequester organic carbon in the soil under optimal conditions of temperature and humidity in natural ecosystems is reduced in the following sequence: leached chernozem > molic brown soil > typical brown soil > typical gray soil > fallow soil – podzol > tundra soil.

At humidities higher or lower than optimal, the ability to sequester carbon in the soil is reduced by 1.2 times. The change in humidity affects the processes of mineralization of organic waste and to a lesser extent of humic substances.

In the absence of organic residues in soils, the intensity of humus mineralization processes intensifies. At the same time, the biogeochemical circuit of carbon in the soil-atmosphere-soil system is influenced by a series of other internal factors (granulometric distribution, total volume and structure of the porous space, degree of compaction, etc.) and external (geomorphological, hydrogeological, climatic etc.). In the agricultural regime it is influenced by the category of use, the structure of the crops, the system of work and fertilization. Therefore, unlike the industrial and anthropogenic circuits that are available for control and limitation, the anthropo-natural one is difficult to control. Moreover, the artificial limitation of the mineralization of organic substances in the soil leads to the reduction of the production process of the crop plants and the reduction of the amount of CO₂ fixed by photosynthesis.

As a result, an unbalanced carbon biogeochemical circuit was established in the chernozems of the Pridanubian space, caused by the reduction of the quantities of fresh humus produced annually in smaller quantities than those consumed in the production of crops (up to 1.6 t / ha / year). Under these conditions, the imperative of soil evolution, in arable and climate change regime, especially chernozems, implies the need to practice agricultural technologies based on the management of the priority role of humus formation and accumulation in the functioning of their bioroutine system. Achieving this goal involves the synchronized solution of problems related to ensuring the stability of agroecosystems, mitigating the effects of climate change and reducing the vulnerability of the agrosphere to climate change.

The main performance indicator of such agricultural technologies is the sequestration of organic carbon in the humus from which it is mobilized on the geological scale of time.

The sequestration of carbon in the composition of humus involves several important components:

- ✓ Pedovegetal - cultivation of plant species with intensive growth and subsequent incorporation of phytomass or part of it into the soil as a source of carbon and biophilic elements;
- ✓ Pedobiochemical - intensifying the production processes of microbial and algal biomass as a source of humus and its humidifying agent;
- ✓ Humus-genetical - intensification of humus formation and accumulation processes. This involves two intercalated mechanisms: humification and stabilization of newly formed humic substances in organo-mineral compounds.

In the context of sequestration of organic carbon in the soil, the aggregation-structuring process has a special role. According to calculations in the humic-cumulative molic horizon (Am) of chernozems, about 90% of the humus reserves are concentrated in the structural aggregates.

Through this prism of ideas, the purpose of this paper involves evaluating the place of humic substances in the aggregation-structuring of the agrogenic layer of typical moderately humiferous chernozems in the central area of the Republic of Moldova, the pedoecological micro-district periphery of the Central Forests.

Objects and methods of study

The research was carried out in production conditions during 2015-2018. The pilot land is characterized by a homogeneous soil cover represented by typical moderately humiferous, moderately thick chernozems with an Am-AmB-Bml-Bca2-BCCA-Cca profile. The soils are characterized by a balanced particle size composition. In its composition the ratio of physical clay: physical sand (<0.01:> 0.01 mm) varies in the range 0.97-1.04 and denotes an increased structuring potential. The dispersion factor on the whole profile varies in a narrow range of values (9.3-11.6%) and indicates low contents (1-2%) of unassociated clay in aggregates (non-aggregate). Under these conditions, from 88.4 to 90.7% of the granulometric elements are associated in agronomically valuable microaggregates with dimensions > 0.01 mm. The granulometric index of IGS structuring in all cases has values of about 100%. The content of agronomically valuable aggregates (0.25-10 mm) has values > 70%. At the same time, however, the content of hydrostable aggregates > 0.25 mm has values <35%. The main factor limiting the realization of the structuring potential is the low humus content. The instability index of the structure (IES = humus content, %: fine clay content (<0.001

mm)), even in the horizon Am makes up only 0.16-0.14. In the BI horizon its values are reduced to 0.08. Under these conditions, the amount of humus is insufficient to ensure the physico-chemical processes of association of elementary particles and microaggregates into structural aggregates. The amount of humus formed annually does not cover the amount of mineralized annually. At the same time, the required content of mobile humic substances that are the main factor of aggregation-structuring of the soil substance is reduced to a minimum (0.18-0.2%). As a result, the soils attest to the uncompensated (regressive) reproduction of the structural-aggregate state. The reduction of the weight of the aggregates formed with the participation of humus leads to the decrease of the hydrostability of the structure. When moistened, the aggregates dissolve easily into microaggregates and

elementary particles. As a result, intensive humus mineralization takes place.

The soil samples subjected to the analyzes were collected from the layer 0-50 cm over every 10 cm at the beginning and end of the vegetation period.

Granulometric analysis was determined by the pipetting method - soil preparation with sodium pyrophosphate. Microaggregate analysis was performed by the pipetting method. The aggregate composition was determined by the Savvinov method (dry fractionation). Aggregate stability was determined by the Savvinov method (wet fractionation). The soil humus content and structural aggregates were determined by the Tiurin method in the Simacov modification.

The scheme of the experimental field is presented in tab. 1.

Table 1 - Scheme of experiences

Culture: Sunflower	Culture: Corn
Control	
<i>Nostoc linckia</i> – 3 kg/ha	<i>Nostoc linckia</i> – 3 kg/ha
<i>Calothrix gracilis</i> - 3 kg/ha	<i>Calothrix gracilis</i> - 3 kg/ha
<i>Nostoc gelatinosum</i> - 3 kg/ha	<i>Nostoc gelatinosum</i> - 3 kg/ha
Combined lot (<i>Nostoc linckia</i> + <i>Calothrix gracilis</i> + <i>N. gelatinosum</i>) – 3 kg/ha	Combined lot (<i>Nostoc linckia</i> + <i>Calothrix gracilis</i> + <i>N. gelatinosum</i>) – 3 kg/ha

Material and discussions

I. Sequestration of organic carbon in the soil.

The process of sequestration-stabilization of organic carbon in the soil is interspersed with the process of humus formation and accumulation. In this context, V. Seminov and B. Kogut distinguish processes of humus formation (formation of organic substances and humus) and humification processes (formation of humic substances) (Seminov V., Kogut B., 2015).

In the opinion of the cited authors, the sequestration - stabilization of organic carbon in the soil represents the totality of processes and phenomena that contribute to increasing the stability of organic substances in relations with biophysical and abiotic factors of decomposition and ensuring a longer period of rotation in soil.

Sequestration-stabilization of the organic substance is performed within a wide range of physical and physico-chemical processes, these being part of the mechanisms of formation of micro- and macro-aggregates.

Z.S. Artemieva and N.P. Chirillova claim that the processes of humus formation in the soil and those of structuring are closely linked, moreover this connection being unidirectional (Artemieva,

Kirilova, 2017). We can assume that the start of the humus formation process is synchronized with the start of the coarse microaggregate formation processes (> 0.01 mm). In this sense, the formation of humus implies its stabilization materialized in the formation of microaggregates, which in turn improve the pedofunctional environment for the process of humus formation. Therefore, the stabilization of organic carbon in microaggregates involves the integration of organic matter (biotic) with the mineral (abiotic) at the lower level (organo-mineral complex) to form the soil aggregate system.

In soils in which the aggregate stabilization is controlled by the organic substance, a directly proportional dependence is achieved between the decomposition of the organic matter and the dynamics of the degree of aggregation.

In the agricultural regime, the disaggregation processes are intensively developed in connection with what changes the microaggregatic composition of the soils.

The research of several authors finds a directly proportional dependence between the organization of microaggregates and the granulometric composition - the degree of microaggregation

increases as the content of physical (> 0.01 mm) and fine (> 0.001 mm) clay in the soil increases.

The mentioned legitimacies materialized in the typification of the organo-mineral complexes of the upper horizon of the zonal soils from the Center of the Russian Platform adapted to the humus state, the

sense of the anthro-po-natural evolution of the chernozems in the Pridanubian space.

Table 2 - Typification of organo-mineral complexes (Артемяева З.С., Семеновна В. И., Силёва Т. М., 2009)

Type. Fine clay content,%	Subtype; Humus content,%			
	1 (0-2)	2 (2-4)	3 (4-6)	4 (>6)
I (0-10)	Slightly clayey, low humiferous	Slightly clayey, moderately humiferous	Slightly clayey, strongly humiferous	Slightly clayey, very strongly humiferous
II (10-20)	Moderately clayey, low humiferous	Moderately clayey, moderately humiferous	Moderately clayey, strongly humiferous	Moderately clayey, very strongly humiferous
III (20-30)	Strongly clayey, low humiferous	Strongly clayey, moderately humiferous	Strongly clayey, strongly humiferous	Strongly clayey, very strongly humiferous
IV (30-40)	Hyper clayey, low humiferous	Hyper clayey, moderately humiferous	Hyper clayey, strongly humiferous	Hyper clayey, very strongly humiferous

The first type (I) is characterized by a high degree of dehumidification and disaggregation, moderate and high degree of destructuring and supercompaction. Soils with such a type of organization of the soil aggregate system are characterized by a maximum degree of agrogenic degradational changes. It has a very high degree of vulnerability to structural degradation and mineralization of humic substances.

Type two (II) is characterized by a moderate degree of dehumidification, a moderate and high degree of disaggregation and destructuring and a large range of variability of the degree of overcompaction. It is characterized by a moderate degree of vulnerability to agrogenic degradation.

Type three (III) is characterized by low and moderate degree of dehumidification and disaggregation, but with a wide range of degree of destructuring and low degree of overcompaction.

Type four (IV) is characterized by low and moderate degree of dehumidification, disaggregation and destructuring, low degree of overcompaction.

Biophysical and chemical processes of stabilization of organic substances and sequestration of carbon in the soil involve the following stages (cited after Seminov and Kogut, 2015).

1) Formation of nuclei from organo-mineral complexes: nuclei of microaggregates can be colonies of microorganisms, the polysaccharide secretions of which form capsules that attract clay

particles to their surface. They cover the capsules and prevent the decomposition of microbial organic matter;

2) Binding of organo-mineral nuclei by means of binders (oxides, hydroxides, clay minerals, humic substances) in microaggregates.

3) Binding of microaggregates to macroaggregates by means of binders with low stability (polysaccharides of microbial and vegetable origin) whose content is dynamic. Their content is maximum during the period of maximum biological activity of soils: April-June (Jigău, 2009).

4) Compaction-consolidation of aggregates under the action of plant roots, fungal hyphae, algae and microorganisms.

In parallel with the processes of aggregate formation, the porous space of the soils is formed. Its dynamics is synchronized with the dynamics of the aggregate composition of the structure.

The physical model of aggregation and sequestration-stabilization of organic carbon in the soil is performed in the same sequence and involves several steps (Fig. 1).

The process of stabilization-sequestration of carbon and soil aggregation starts from the adhesion of elementary particles / microaggregates through microorganisms / algae on the surface of fresh plant residues with the formation of macroaggregates (stage 1).

The processes of transformation-decomposition of organic matter in aggregate pores lead to the formation of physically stable organo-mineral nuclei, protected by the action of mineralization processes (stage 2). Over time, as the reserves of organic matter, slightly decomposed, slowly deplete, microbial activity is reduced, and as a result the amount of binders (stage 3).

Consequently, the processes of destabilization and disaggregation of macroaggregates start, and new microaggregates are formed from the organo-mineral nuclei inside them, which can be involved in

creating new microaggregates in the conditions of fresh organic matter flows (Stage 4).

Through this prism of ideas, aggregation-structuring is the main process of physical stabilization of organic carbon in the soil, and structural aggregates represent pedogenetic formations that sequester and stabilize organic carbon in the soil. In this sense, the structural aggregates are organo-mineral complexes formed as a result of the interaction of organic and mineral elementary particles within the processes of structural organization of the soil aggregate system (Fig. 2 – 3).

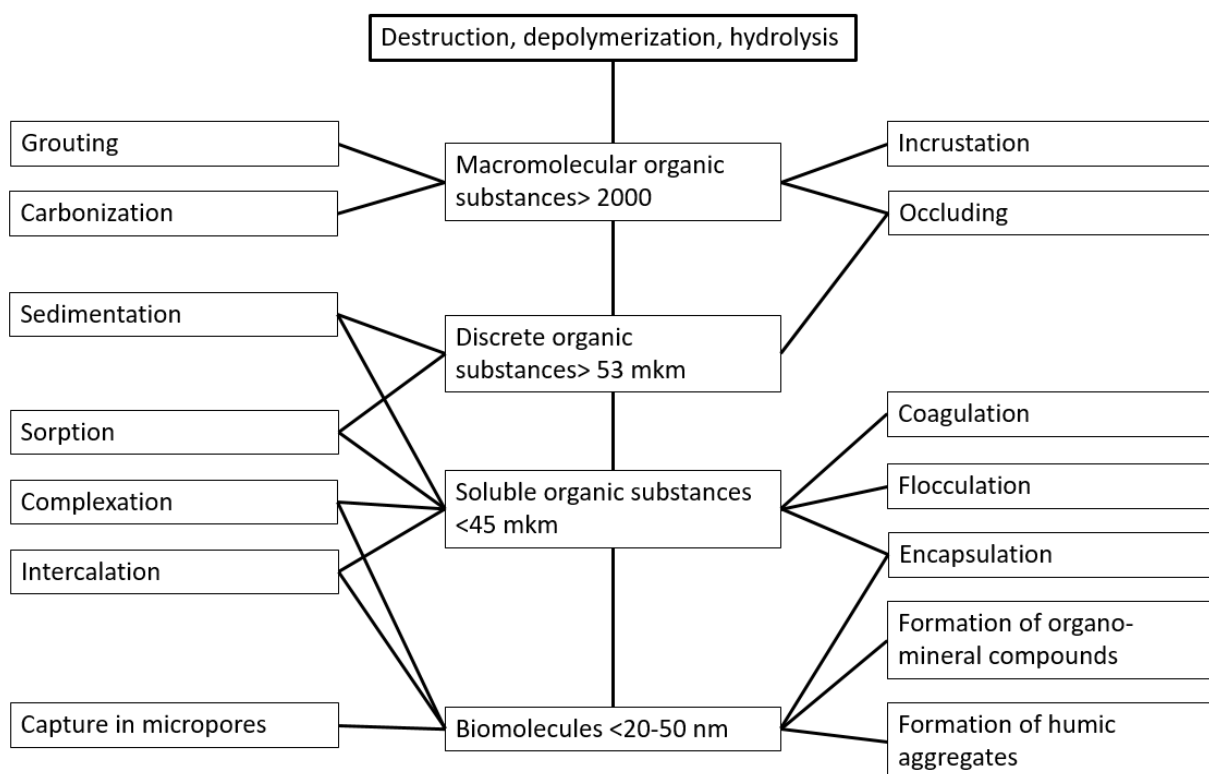


Fig. 1 - Physico-chemical and physical processes of stabilization-sequestration of organic substances in soils

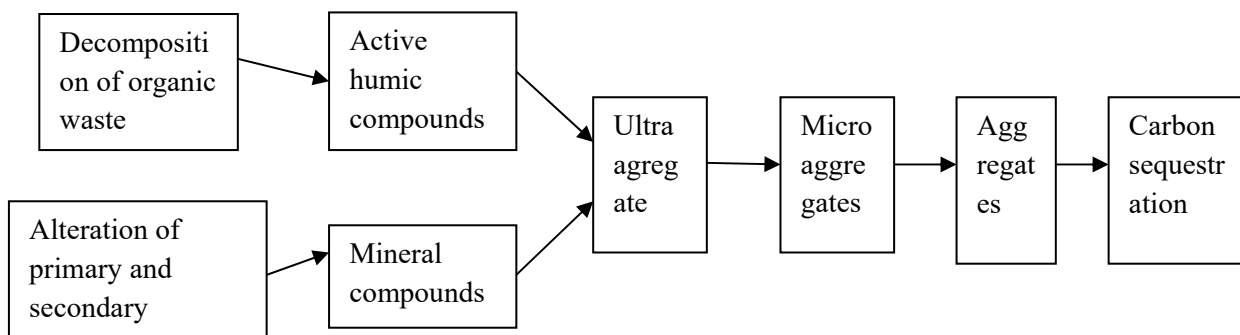


Fig. 2 - Mechanisms of sequestration of organic carbon in the soil within the aggregation-structuring processes

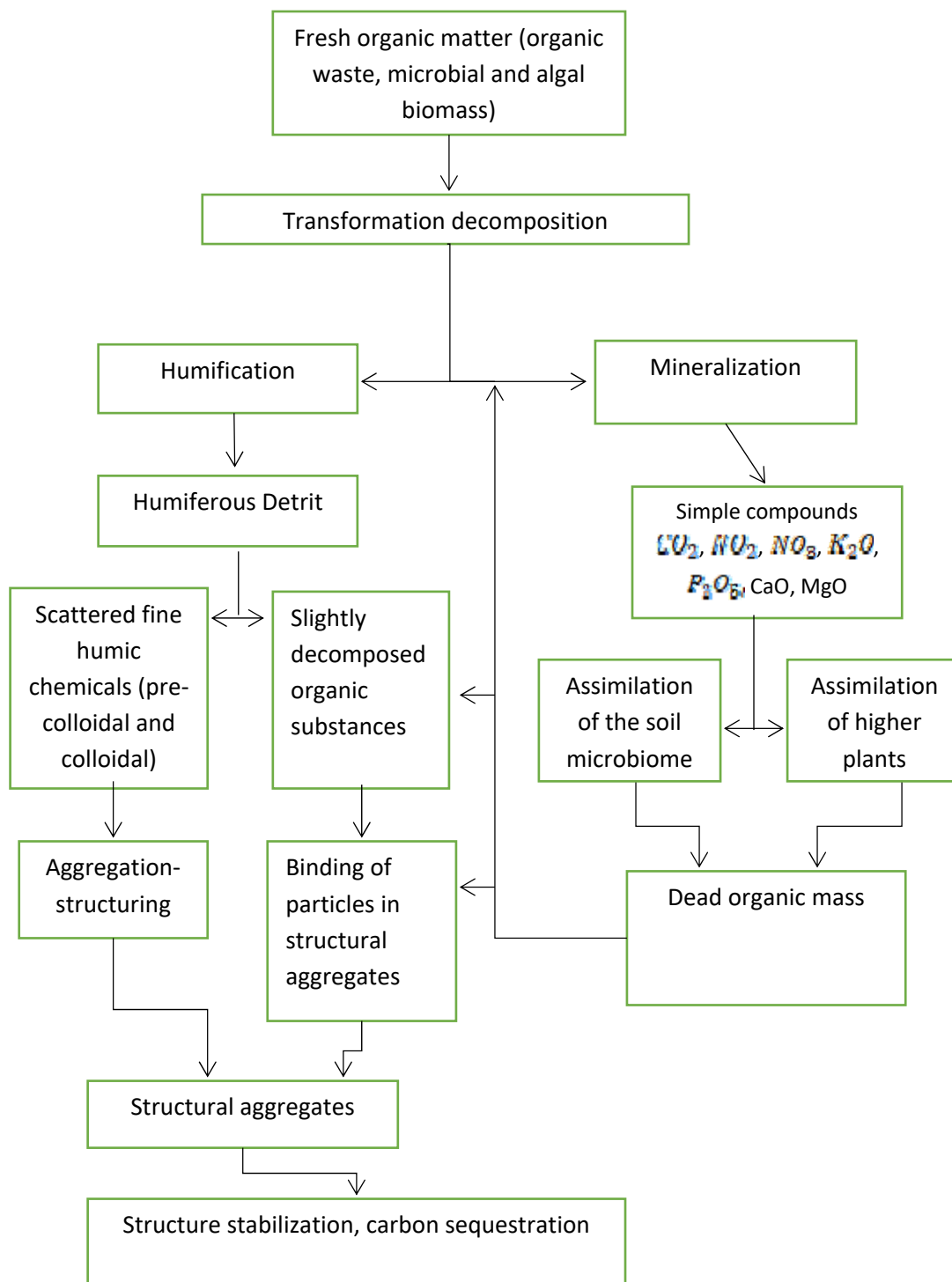


Fig. 3 - The pedofunctional chain of sequestration of organic carbon in the soil

The structural aggregates differ from each other by the mechanisms of the dominant aggregation processes, shape, dimensions and are divided into: organo-mineral colloids (<20 mKm), microaggregates (20-250 mKm), macroaggregates (250-2000 mKm) and fragments (> 2000 mKm).

Organic substances present in microaggregates are older, have a more advanced degree of decomposition and are more protected than those contained in macroaggregates, caused by the spatial division of the substrate and microorganisms: the maximum density of microorganism populations is on the surface of aggregates and the maximum weight of organic matter is concentrated in the aggregate pores / inside the aggregates. The duration of the rotation period of the organic substances contained in macroaggregates is 15-50 years, and of the one contained in microaggregates is 100-300 years.

The processes of aggregation and sequestration-stabilization of organic carbon are controlled primarily by the flow of fresh organic matter in the soil, which determines the activity of meso-microfauna and microorganisms. At the same time, it is shown that organic matter, in the decomposition stage, is a more efficient aggregating agent, compared to humic substances, whose role is to support aggregate stability.

In this sense, for the formation and conservation of the aggregate structure is important not so much the amount of organic matter in the soil as much as the amount of its biologically and chemically modified forms.

This implies the permanent presence of decomposing organic matter. In agroecosystem conditions, this objective is practically unattainable during the vegetation period, or the organic residues are incorporated in the soil only at the end of the vegetation period. Instead, organic residues of microbial and algal origin are permanently present in the soil. Their sustainability during the vegetation period ensures the permanent supply of organic matter capable of ensuring the reproduction of the structural-aggregate condition of the soils. These processes are supported by the increased nitrogen content in the composition of algal and microbial biomass.

II. Case Study. Sequences of sequestration-stabilization of organic carbon in the processes of aggregation-structuring with the participation of algae.

In accordance with the concept of aggregation-structuring mechanisms described above, we consider that aggregation-structuring with the participation of nitrogen-fixing cyanophyte algae includes several evolutionary-hierarchical stages:

1. Elementary particle $\frac{\text{algae}}{\text{microbiota}}$ microaggregate (<0.25mm);
2. Microaggregates $\frac{\text{algae}}{\text{microbiota, humic substances}}$ elementary particle → aggregates (1-0.25 mm);
3. Aggregates (1-0.25 mm) - humic substances - aggregates (1-0.25 mm) → aggregates (7-1 mm).

The aggregation-structuring process of chernozems with the participation of algae is accompanied by the formation of three groups of aggregates:

- a) With low stability - 7-5 mm;
- b) With moderate stability - 5-1 mm;
- c) With increased stability - 1-0.25 mm.

In the development of this concept we consider that a more important role in the formation of structural aggregates belongs to their interaction within the complex matter (substance) organic-microorganisms.

Within them, there are permanent processes of formation of fresh humic substances that ensure the in situ aggregation. As a basic component (nucleus) of microbial cenoses, nitrogen-fixing cyanophyte algae lead to the formation of associations of organisms responsible for the decomposition of different groups of organic substances (geno-metabolic networks) that decompose organic residues, thus ensuring a circuit closed of substances and energy with the development of the aggregate level of structural-functional organization of the organo-mineral matter of the soil.

Our research has shown that the biomass of all species of nitrogen-fixing algae experienced contributes to the aggregation - structuring of soil pedometrics. At the same time, the aggregation-structuring effects differ from one species to another (tab. 2)

Tab. 2 - Aggregate composition of the typical moderately humiferous chernozem under algalization conditions (non-irrigated regime; average values for layer 0-30 cm)

Variant	Diameter of aggregates, mm. Content of % aggregates					K_g
	>10	10-0,25	5-1	3-0,5	<0,25	
Corn culture						
Witness	17,91	77,57	42,42	30,36	4,37	3,46
<i>Nostoc linckia</i>	10,70	84,39	46,25	32,96	4,59	5,58
<i>Nostoc gelatinosum</i>	9,80	86,95	49,50	33,78	4,27	7,09
<i>Calothrix gracilis</i>	15,42	81,67	44,58	33,53	4,16	4,58
<i>Cylindrospermum licheniforme</i>	13,09	82,81	46,57	32,29	5,50	4,83
Combined lot	11,92	84,97	48,05	33,06	3,47	6,29
Sunflower culture						
Witness	10,38	78,82	40,69	33,25	10,83	4,17
<i>Nostoc linckia</i>	14,52	77,84	41,67	36,16	7,74	3,51
<i>Nostoc gelatinosum</i>	9,23	87,70	56,12	34,84	4,01	7,27
<i>Calothrix gracilis</i>	12,64	81,21	54,16	32,51	6,15	4,41
<i>Cylindrospermum licheniforme</i>	13,09	83,01	43,04	32,55	6,08	5,58
Combined lot	10,62	86,06	47,74	33,45	3,39	6,42

K_g - structuring coefficient.

The most intensive aggregation-structuring processes take place with the participation of the species *Nostoc gelatinosum* on the entire thickness of the layer 0-50 cm with the formation of aggregates 5-1 and 3-0.5 mm. This is due to the agglutination process with the participation of newly

formed humic substances with the increase of the degree of protection and sequestration of carbon in the structural aggregates. At the same time, however, the newly formed aggregates have reduced hydrostability, as a result of a refined composition (Table 3).

Table 3 - Aggregate stability of the structure of the typical humiferous moderate chernozem in algalization conditions (non-irrigated regime) average values for the start 0-30 cm

Variant	Diameter of aggregates, mm. Content of aggregates%.				K_g
	>5	5-1	3-0,5	1-0,5	
Corn culture					
Witness	-	23.67	24.03	8.83	232
<i>Nostoc linckia</i>	-	22.13	27.87	11.80	220
<i>Nostoc gelatinosum</i>	-	28.29	32.67	15.17	516
<i>Calothrix gracilis</i>	-	23.62	28.36	13.70	517
<i>Cylindrospermum licheniforme</i>	-	29.43	37.94	15.32	457
Combined lot	-	26.12	33.12	14.20	501
Sunflower culture					
Witness	-	17.84	21.95	9.35	230
<i>Nostoc linckia</i>	4.30	34.80	34.66	16.41	216
<i>Nostoc gelatinosum</i>	6.46	34.60	37.71	18.07	442
<i>Calothrix gracilis</i>	5.18	26.15	33.70	16.32	460
<i>Cylindrospermum licheniforme</i>	4.80	43.04	33.00	16.70	305
Combined lot	4.88	49.41	38.18	17.50	537

K_g - hydrostability index.

Within natural ecosystems, the aggregation-structuring process also takes place with the formation of loose aggregates. Subsequently, however, they are subjected to compaction-consolidation under the action of forces exerted by the root system of herbaceous plants. The influence of plants is achieved both by the mechanical actions of the root system (particle displacement, compaction, etc.) and of various substances (metabolites) formed as a result of their vital activity.

The culture plants provide to a small extent the described processes and have a different action on the aggregation-structuring processes of the biopedoplasm with the participation of nitrogen-fixing cyanophyte algae.

In general, the intensity of the process of sequestration-stabilization of organic carbon in the soil can be reproduced with the following pedofunctional rows in the sense of decreasing it:

Corn: *Nostoc gelatinosum* > *Calothrix gracilis* > Combined lot > *Cylindrospermum licheniforme* > *Nostoc linckia*;

Sunflower: *Nostoc gelatinosum* > Combined lot > *Cylindrospermum licheniforme* > *Calothrix gracilis* > *Nostoc linckia*.

Conclusions

1. The processes of aggregation-structuring of the biopedoplasm of chernozems lead to the formation of pedogenetic formations (structural aggregates), in which organic substances are protected from mineralization.

2. The physico-chemical, chemical and biophysical mechanisms of the carbon circuit depend on the intensity of the humus formation and accumulation processes. The process of organizing the aggregate system of chernozems represents a hierarchically evolutionary row: organo-mineral complex (ultramicroaggregate) - microaggregate - aggregates 1-0.25 mm - aggregates 7-1 mm. Aggregates > 7 mm represent fragments of mechanical origin.

3. The destructuring-disaggregation processes proceed in the opposite direction with the

intensification of the humus mineralization processes.

4. The algalization process contributes to the aggregation-structuring of the sequestration-stabilization processes of organic carbon in the soil. The aggregates formed in algalization conditions have a refined organization and reduced hydrostability.

5. Crop plants to a small extent contribute to the compaction-consolidation of newly formed aggregates. In order to increase the degree of compaction-consolidation of the newly formed structural aggregates, it is recommended to include multiannual grasses in the crop structure and to administer in the soil once in 4 years 5 t / ha of calcium amendments -waste from the sugar industry and the thermal energy branch.

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