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Evaluation of structural aggregation processes of typical chernozem under conditions of algal biofertilizers application

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Abstract: The management of the aggregation-structuring processes implies the intensification of the soil pedoplasm modeling processes under the direct and indirect action of the its biota. In the present research we started from the consideration of algal microflora as the nucleus of bacterial-algal cenosis responsible for the decomposition of various groups of organic substances (geno-metabolic networks). They decompose organic waste in consecutive series ensuring a closed circuit of substances and energy with development of the aggregate level of structural-functional organization of the soil organo-mineral biopedoplasm. It has been established that algalization of the typical moderately humiferous strongly overplowed chernozem through administration of algal biopreparations leads to the regeneration of the humification process and the improvement of the structural-aggregate condition of the soil. The mechanisms of this process are determined by the participation of algal biomass as a source of biological nitrogen for the humification process. Under algalization conditions, the aggregation processes proceed with the formation, mainly, of 5-1 and 3-0.5 mm aggregates and are determined by the agglutination processes with the participation of newly formed humic substances. The intensity of the aggregation-structuring processes differs depending on the species of administered cyanophyte algae and can be described with the following sequence in the sense of decreasing it: *Nostoc gelatinosum* > Combined lot > *Cilindrospermum licheniforme* > *Calothrix gracilis* > *Nostoc linckia*. The cyanophyte algae participate less in the direct aggregation processes of soil biopedoplasm. At the same time, the practiced technologies require crop rotations capable of contributing to increasing the degree of aggregate stability. In the pedofunctional aspect, the process of algalization of chernozems presupposes perspectives for sustaining the composition and diversity of the soil microbiome.

1. Introduction

Aggregate soil composition is the main factor that determines the volume, structure, stability and continuity of the porous space, which conditions the pedofunctional regimes (hydrothermal, aerohydric, hydric, aeration, reductive and biological) responsible for the meaning and intensity of chernozem evolution processes and their natural fertility.

Namely through the structure of the soil can be managed its porous space, respectively the processes that take place in the soil.

Mechanical stability and aggregate hydrostability determine the stability of the structural-aggregate organization mode, over time, as well as the stability in the relations with the processes of physical soil degradation (Jigău and Leşanu, 2021).

Our research has shown that in the aggregation and structuring of the soil the decisive role belongs to fresh humic substances. The formation and development of the structure is dependent not only of presence of organic matter in the soil but also of its modified biological and chemical forms (Jigău, 2009). Within them, there are permanent processes for the formation of fresh humic substances that ensure the "in situ" aggregation. As a basic component (nucleus) of 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 waste consecutively ensuring a closed circuit of substances and energy with the development of the aggregate level of structural-functional organization of the mineral organic matter of the soil (Зубкова, Карпачевский, 2001; Прудникова, 2015).

2. Materials and Methods

The research included field and laboratory activities.

The field activities took place in the agricultural holding LLC "Vindex Agro" from Orhei district, the Republic of Moldova. The researched lands belong to the second terrace of the Raut river and characterized by relatively homogeneous soil cover represented by typical low humiferous chernozems, mostly loamy clays with varying degrees of overplowing depending on the category of use.

Morphologically, in the composition of the profile the agrogenic layer Aph1 + Aph2 with a thickness between 40 and 50 cm is clearly outlined. Its composition can be distinguished the arable layer with a thickness of 27-33 cm and the underlying hardpaned layer.

The arable layer is characterized by a high content (70-80%) of agronomically valuable aggregates (10-0.25 mm) in the composition of which 5-1 mm aggregates makes up 38%-46%. At the same time, however, more than 1/3 of them belong to pseudoaggregates of agrogenic origin lacking hydrostability.

In the subarable layer the content of agronomically valuable aggregates makes up 60-70%. In their composition there is a slight increase in the content of hydrostable aggregates, however, they are represented by pseudoaggregates formed by compensatory-deforming mechanisms and are characterized by an increased degree of compaction and aggregate porosity below 30%.

A total of 6 variants with live biomass administration of nitrogen-fixing cyanophyte algae species were tested, as follows: 1. *Nostoc linckia*; 2. *Calothrix gracilis*; 3. *Cylindrospermum licheniforme*; 4. *Nostoc gelatinosum*; 5. The combined variant (*Nostoc linckia* + *Nostoc gelatinosum* + *Calothrix gragilis* + *Cylindrospermum licheniforme*); 6. The control plot (in which no algae were administered). The algal biomass was administered on the ground, in suspension, in a dose of 3 kg/ha, in the early stages of development of the sunflower plants (agricultural year 2017-2018) in non-irrigated regime.

The structural-aggregate analysis was performed by use of the Savvinov method with the determination of the aggregate composition (dry sieving) and the aggregate stability (wet sieving).

The humus content in the structural aggregates was determined by the Tiurin method in the Simacov modification, which is based on the oxidation of humus with 0.4 n solution of potassium dichromate $K_2Cr_2O_7 + H_2SO_4$ (Кауричев, 1980).

3. Results and discussions

Research has shown that the biomass of all tested species of nitrogen-fixing cyanophyte algae contributes to the structuring of soil mass. At the same time, however, the data presented in Table 1 shows that the effects of structural aggregation differ from one species to another.

The application of *Nostoc linckia* algae biomass contributes to the formation of higher contents of agronomically valuable aggregates (10-0.25 mm) in the 10-30 cm layer, which is due to the more favorable humidity conditions. The aggregation-structuring processes of the soil biopedomatrix with the participation of the *Nostoc linckia* species take place with the predominant formation of aggregates <5 mm, which thanks to an optimal structure of the porous space favors the development of the root system of the crop plants. At the same time, the data in Table 1 shows that the aggregates <5 mm in this variant have relatively low soil aggregate stability.

Table 1. Structural-aggregate composition of the typical moderately humuferous silt loamy chernozem at the end of the vegetation period under biofertilization conditions with biomass of nitrogen-fixing cyanophyte algae

Variant	Depth (cm)	Way of operation	Aggregate diameter (mm) aggregate content (%)								
			>10	10-7	7-5	5-3	3-2	2-1	1-0.5	0.5-0.25	<0.25
Witness	0-10	Dry	13.77	10.68	6.39	8.83	8.09	18.80	7.47	8.83	17.14
		Wet	-	-	-	11.59	10.38	2.66	6.85	18.08	50.45
		+/-	-	-	-	-2.76	-2.29	16.14	0.62	-9.25	-33.3
	10-20	Dry	5.94	13.80	10.86	16.26	12.65	19.95	4.58	5.90	10.06
		Wet	-	-	-	4.00	8.67	3.14	6.87	16.23	61.08
		+/-	-	-	-	12.26	8.07	6.81	-2.29	-10.33	-51.2
	20-30	Dry	11.43	14.44	17.82	25.47	11.11	13.91	3.21	3.33	5.08
		Wet	-	-	-	0.11	6.11	6.85	14.33	16.77	55.83
		+/-	-	-	-	20.36	4.99	7.06	-11.11	-13.44	-50.76
	30-40	Dry	13.92	11.67	12.69	12.66	17.46	14.68	2.22	2.12	2.58
		Wet	-	-	-	4.52	2.29	16.34	11.80	18.00	46.39
		+/-	-	-	-	18.14	14.52	1.66	9.58	15.88	43.81
	40-50	Dry	9.43	6.55	14.56	31.91	20.85	12.89	1.67	0.99	1.15
		Wet	-	-	-	12.95	2.69	2.23	14.73	18.47	48.92
		+/-	-	-	-	18.14	14.52	1.66	-9.58	-15.88	-43.81
Nostoc linckia	0-10	Dry	22.11	15.24	6.27	9.09	8.11	17.10	6.12	6.70	9.20
		Wet	-	-	3.08	13.00	14.33	2.71	20.89	23.98	20.99
		+/-	-	-	3.19	-3.91	-6.22	14.39	-14.77	-17.28	-12.74
	10-20	Dry	10.99	13.20	9.38	13.36	11.26	17.15	7.43	6.94	10.29
		Wet	-	-	3.08	13.00	14.33	2.71	20.89	23.98	20.99
		+/-	-	-	5.37	-3.36	-7.69	10.92	-0.48	-5.86	-23.09
	20-30	Dry	10.47	13.16	11.57	17.80	12.70	18.45	10.16	1.97	3.72
		Wet	-	-	5.82	19.94	3.24	9.30	20.44	27.92	69.44
		+/-	-	-	5.75	-2.14	9.46	9.14	-10.28	-25.95	-65.72
	30-40	Dry	26.68	17.82	10.58	14.86	10.08	12.41	8.45	2.33	6.79
		Wet	-	-	-	0.3	17.81	13.69	21.05	37.74	9.07
		+/-	-	-	-	10.56	-7.73	-1.28	-12.60	-35.41	-2.28
	40-50	Dry	6.32	8.95	12.18	24.56	23.45	17.40	2.85	2.35	1.94
		Wet	-	-	-	10.81	3.55	26.33	22.41	21.82	15.07
		+/-	-	-	-	13.75	19.90	-8.93	-19.56	-19.47	-13.13
Nostoc gelatinosum	0-10	Dry	13.38	14.73	11.57	14.26	10.37	18.93	5.34	6.56	4.89
		Wet	-	-	-	16.56	18.70	6.73	16.87	21.76	19.38
		+/-	-	-	-	-2.36	-8.33	12.20	11.53	-15.23	-14.49
	10-20	Dry	7.57	19.03	15.54	21.08	13.58	14.17	3.64	2.56	2.83
		Wet	-	-	6.92	11.48	3.60	6.67	13.32	25.73	32.28
		+/-	-	-	8.62	9.60	9.90	7.50	-9.68	-23.17	-29.45
	20-30	Dry	6.74	11.55	11.76	23.33	15.67	17.75	5.07	4.59	3.54
		Wet	-	-	7.12	10.37	14.93	5.48	16.74	22.44	17.92
		+/-	-	-	4.64	13.00	0.74	12.27	-11.67	-22.85	-14.38

Variant	Depth (cm)	Way of operation	Aggregate diameter (mm) aggregate content (%) >10	10-7	7-5	5-3	3-2	2-1	1-0.5	0.5-0.25	<0.25
	30-40	Dry	3.39	7.04	13.35	25.03	22.65	20.30	3.52	2.96	1.76
		Wet	-	-	4.50	6.85	17.32	12.04	18.53	28.28	12.48
		+/-	-	-	8.85	18.18	5.33	8.26	-15.01	-25.32	-10.72
	40-50	Dry	1.91	10.41	13.03	21.23	24.38	18.33	3.58	2.25	4.88
		Wet	-	-	3.08	9.10	5.29	21.96	14.73	16.48	29.36
		+/-			9.95	12.13	19.09	-3.63	-11.15	-14.23	-24.48
Calothrix gracilis	0-10	Dry	16.85	14.56	9.08	17.64	11.04	15.27	3.86	6.24	4.74
		Wet	-	-	5.17	12.98	3.90	5.62	14.92	20.53	36.88
		+/-	-	-	4.63	4.66	7.14	9.56	-11.06	-14.29	-32.14
	10-20	Dry	10.33	16.78	16.50	19.69	10.08	10.80	3.61	3.60	8.61
		Wet	-	-	6.01	5.81	9.16	3.21	14.10	23.36	38.50
		+/-	-	-	10.49	13.88	0.92	7.59	-10.49	-19.76	-29.89
	20-30	Dry	10.74	14.06	13.06	21.39	14.38	14.74	3.30	2.79	5.09
		Wet	-	-	4.32	10.51	18.61	8.66	19.91	20.10	17.89
		+/-	-	-	8.74	10.88	-3.78	6.08	-16.61	-17.31	-12.80
	30-40	Dry	3.38	7.80	12.43	24.50	26.50	16.44	2.53	1.84	4.58
		Wet	-	-	4.48	5.03	6.10	17.40	19.87	20.10	27.02
		+/-	-	-	7.95	19.47	20.40	-0.96	-17.34	-18.26	-22.44
	40-50	Dry	9.88	12.00	11.03	20.76	21.23	17.52	2.14	1.66	3.78
		Wet	-	-	4.00	5.81	11.46	13.38	26.39	19.13	19.83
		+/-	-	-	7.03	14.95	9.77	4.14	-24.25	-17.47	-16.05
Cylindrospermum licheniforme	0-10	Dry	18.65	15.46	9.80	11.35	7.28	14.16	9.10	7.11	7.09
		Wet	-	-	6.59	2.51	18.28	1.69	9.91	22.50	35.52
		+/-	-	-	3.21	8.84	-11.00	12.47	-0.81	-18.39	-28.43
	10-20	Dry	12.40	14.35	11.27	20.26	12.37	14.00	4.21	4.40	6.74
		Wet	-	-	3.00	8.26	14.53	5.54	12.60	20.79	35.37
		+/-	-	-	8.27	12.00	-2.16	8.55	-8.39	-16.39	-28.63
	20-30	Dry	8.22	15.51	12.40	18.60	15.03	16.07	5.44	4.29	4.40
		Wet	-	-	-	8.46	21.33	5.94	27.60	24.69	11.98
		+/-	-	-	-	10.14	-6.33	10.13	-22.16	-20.40	-7.58
	30-40	Dry	8.04	9.44	11.78	19.80	21.17	18.85	3.08	3.64	4.10
		Wet	-	-	-	5.10	19.12	14.49	18.06	27.92	15.31
		+/-	-	-	-	14.70	2.05	4.36	-14.98	-24.28	-11.21
	40-50	Dry	9.74	14.46	14.63	24.04	20.50	11.74	1.54	1.90	1.45
		Wet	-	-	-	5.48	3.22	25.35	16.46	22.80	28.69
		+/-	-	-	-	18.56	17.28	-13.61	-14.29	-20.90	-27.24
Combined variant	0-10	Dry	10.68	17.08	9.56	4.54	6.68	25.48	6.03	6.76	6.19
		Wet	-	-	5.68	3.75	4.67	8.50	19.35	20.16	37.89
		+/-	-	-	3.88	7.79	2.01	16.98	-13.32	-13.40	-31.70
	10-20	Dry	13.53	18.85	13.70	21.76	13.93	10.27	3.84	3.01	1.11
		Wet	-	-	4.39	15.41	18.75	5.70	15.29	15.94	24.52
		+/-	-	-	9.31	6.5	-4.82	4.57	-11.45	-12.93	-23.41
	20-30	Dry	7.64	13.04	14.38	26.39	17.02	15.17	1.95	1.54	2.87
		Wet	-	-	4.56	4.84	17.95	12.50	17.87	29.79	12.49
		+/-	-	-	9.82	21.55	-0.93	2.67	-15.92	-28.25	-9.62
	30-40	Dry	6.60	10.32	13.02	26.72	21.34	14.00	2.30	2.00	3.70
		Wet	-	-	3.91	4084	17.59	10.15	18.87	27.79	16.85
		+/-	-	-	9.11	21.88	3.75	3.85	-16.57	-25.79	-13.15

Variant	Depth (cm)	Way of operation	Aggregate diameter (mm) aggregate content (%)								
			>10	10-7	7-5	5-3	3-2	2-1	1-0.5	0.5-0.25	<0.25
	40-50	Dry	5.56	12.22	11.03	21.35	20.87	17.13	3.23	3.55	4.79
		Wet	-	-	-	4.29	16.09	17.97	18.68	5.97	36.37
		+/-	-	-	-	16.43	4.78	-0.84	-15.45	-2.42	-31.40

[1]The value with the sign „–" indicates the increase of the content of hydrostable aggregates with the respective dimensions at the expense of the disintegration of the aggregates. The value with the „+" sign indicates the reduction of the hydrostability of the aggregates with the respective dimensions (Качинский, 1965).

The application of the algae biomass *Calothrix gracilis* contributes to the aggregation-structuring of the biopedoplasm over the entire thickness of the arable layer (0-30 cm). The aggregation-structuring processes with the participation of this species ensure the predominant formation of 10-0.25 mm aggregates. At the same time, the weight of the 5-1 and 3-0.5 mm aggregates is less than 50%. Aggregates > 5 mm (which are characterized by very low hydrostability) have a higher weight, and more often they lack hydrostability.

The application of *Cylindrospermum licheniforme* algae biomass contributes to the process of aggregation-structuring of the biopedoplasm only in the first 0-20/0-30 cm. The aggregation-structuring of the biopedoplasm with the participation of this species results in the formation of medium and fine blocky aggregates, at the expense of which the degree of structuring increases. Despite this fact, in the structural-aggregate composition the content of glomerular aggregates is low, which leads to a lower degree of quality of the soil structure.

In the variant with the combined administration of algal biofertilizers, the improvement of the soil structure on the entire thickness of the agrogenic layer from the account of medium and fine blocky aggregates with only satisfactory hydrostability is attested.

The structuring processes are most intensive with the participation of the species *Nostoc gelatinosum*. From the data presented in table 1 we find that the aggregation-structuring processes of the biopedoplasm flow intensively over the entire thickness of the agrogenic substrate and the underlying substrate (30-50 cm) with the formation of aggregates with a diameter of 5-1 and 3-0.5 mm. This is due to the agglutination process with the participation of newly formed humic substances. As a result, the carbon sequestration process takes place. At the same time, the newly formed aggregates have low stability. This implies the need for concomitant administration of an additional source of calcium.

Based on the above, we can conclude that all the studied algae species contribute to the aggregation-structuring of the biopedoplasm with the formation of lumpy and grainy aggregates. At the same time, they have a low stability due to a diffuse (loose) composition. In natural ecosystems, the aggregation-structuring process also proceeds with the formation of loose aggregates. Their stability is ensured by their consolidation under the action of forces exerted by the root system of the herbaceous plants (Шеин Е.В., Милановский Е.Ю., 2014). Under agroecosystem conditions, the role of the plant root system in consolidating structural aggregates is significantly reduced. Therefore, we consider it opportune, in algalization conditions, the periodic administration of some accessible sources of calcium (2.5-3.0 t / ha) sufficient for the formation of fresh humates with calcium (Jigău and Leșanu, 2021)

The influence of plants is achieved both by the mechanical actions of the root system (particle displacement, compaction, loosening, etc.) and the various substances (metabolites) formed as a result of their vital activity.

Crop plants assure less the described processes. Based on this, we consider it appropriate to use algal preparations in combination with measures to improve the phytoimprovement of chernozems by cultivating perennial grasses.

Aggregates >10 and <0.25 mm are characterized by a minimum humus content (Jigău Gh., 2009). Aggregates >10 mm are characterized by a high share of aeration pores (> 95%) which favors the predominant realization of the processes of mineralization of organic resources that are presented in them.

Aggregates <0.25 mm have very fine porosity (<0.2 μ) which are occupied by physically bound water, inaccessible to plants but also to soil biota. As a result, they do not carry out biological and biochemical processes that would lead to the accumulation of humus.

Aggregates 1-0.5 and 0.5-0.25 mm are characterized by high humus contents because they are composed mainly of particle size 0.005-0.001 mm in which are concentrated the main reserves of humus present in the soil (Lupașcu and Jigău, 1998). Aggregates 1-0.5 and 0.5-0.25 mm represent the reserve for the formation of aggregates 3-1 mm. Due to this, the 3-1 mm aggregates are characterized by a maximum humus content (Table 2). The analysis of the hydrostability indices of the structural aggregates of the typical chernozems within the experimental groups shows that at wetting the 3-10 mm aggregates are mainly divided into 3-0.5 and 0.5-0.25 mm aggregates (Table 1). This implies the conclusion that the 10-0.25 mm aggregates are mainly composed of 3-0.5 and 0.5-0.25 mm aggregates. Therefore, given that the structural aggregates 10-0.25 mm in the structural-aggregate composition of the soils within the experimental lots account for between 70% and 90% (with small exceptions) we can consider that in them are concentrated the main humus reserves.

Table 1. Humus content in structural aggregates of typical chernozem under conditions of application of biofertilizer from biomass of nitrogen-fixing cyanophyte algae

Depth, cm	**Variant, culture**	**Humus content, %**	**Size of aggregates (cm), humus content (%)**																	
			>10		**10-7**		**7-5**		**5-3**		**3-2**		**2-1**		**1-0,5**		**0,5-0,25**		**< 0,25**	
			1*	2*	1*	2*	1*	2*	1*	2*	1*	2*	1*	2*	1*	2*	1*	2*	1*	2*
0-10	**Witness**	**1,88**	1,41	7,5	1,43	7,6	1,57	8,4	1,78	9,5	1,98	10,5	2,03	10,8	2,11	11,2	2,00	10,6	1,57	8,4
10-2		**2,40**	2,13	8,9	2,67	9,4	2,34	9,8	2,40	10,0	2,57	10,7	2,,70	11,3	2,70	11,3	2,29	9,5	1,98	8,3
20-3		**2,35**	2,00	8,5	2,03	8,6	2,12	9,0	2,27	9,7	2,35	10,0	2,52	10,7	2,67	11,4	2,17	9,2	1,80	7,7
0-10	**Combined lot**	**2,53**	2,44	9,6	2,47	9,8	2,51	9,9	2,71	10,7	2,96	11,7	3,17	12,5	2,98	11,8	2,58	10,2	2,24	8,9
10-2		**2,57**	2,48	9,6	2,51	9,8	2,55	9,9	2,70	10,5	3,03	11,8	3,29	12,8	2,74	10,7	2,67	10,4	2,28	8,8
20-3		**2,40**	2,30	9,6	2,32	9,7	2,38	9,9	2,51	10,5	2,80	11,7	2,91	12,1	2,63	11,0	2,50	10,4	2,12	9,04

1 * - humus content (%); 2 * - share of aggregates (%).

It is worth mentioning that in the variants with algal biomass administration the increase of humus content was attested. The most significant values were attested in the combined version, the results of which are presented in Table 2.

From the presented data we find that in more intensive algalization conditions the aggregation processes with the formation of aggregates 5-1 and 3-0.5 mm take place.

This is due to the agglutination process with the participation of newly formed humic substances. At the same time, based on the obtained results, we find that the newly formed structure has low hydrostability, because the aggregation-structuring proceeds with the formation of lumpy and granular aggregates with loose composition.

At the same time, research shows that cultivated plants have a different effect on the aggregation-structuring processes. In general, the intensity of the monitored processes can be reproduced with the following pedofunctional sequence in the sense of decreasing it: *Nostoc gelatinosum* › Combined variant › *Cylindrospermum licheniforme* › *Calothrix gracilis* › *Nostoc linckia*.

Thus, it has been found that algal populations in the biocenosis (for example the cyanophytes of nitrogen-fixing algae tested in the research) influence the biotope (referring to the soil) and considerably increase the chances of the soil to maintain its ecological balance.

4. Conclusions

Algalization of the typical moderately humiferous strongly overplowed chernozem by the administration of biofertilizers based on nitrogen-fixing cyanophyte algae leads to the regeneration of the humification process and the improvement of the structural-aggregate condition of the soil. It was established that the quantitative and qualitative effects in the evolution of the structural-aggregate condition in all cases lead to its improvement materialized in increasing the content of valuable agronomic aggregates (0.25-10.0 mm) with the predominant formation of aggregates 5-1 and 3-0.5 mm. At the same time, they differ depending on the species of algae administered. More intensively, the aggregation-structuring processes take place with the participation of the species *Nostoc gelatinosum* and lead to the formation of relatively stable aggregates <5 mm. The mechanisms of this process are determined by the participation of the altered algal biomass as a source of biological nitrogen for the development of the humification process. In a less, degree the cyanophyte algae participate in the direct aggregation processes of the soil biopedomatrix. Their systemic use presupposes perspectives for sustaining the composition and diversity of the soil microbiome. At the same time, the aggregation-structuring process in algalization conditions is influenced by the cultivated crops.

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