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FORMATION OF SOIL STRUCTURE OF CHERNOZEMS IN DIFFERENT AGROECOSYSTEMS

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Abstract

In order to preserve the satisfactory functioning of agroecosystems of the Left Bank of Ukraine in the context of global warming, based on the results of soil structure formation studies, proposals can be made for the reproduction of fertility and protection of chernozem soils and rational land use. Soil organic matter and soil biota have a leading influence in soil structure formation. It is established that the best structured variants of agroecosystems with the addition of organic and organo-mineral fertilizers. Such agrochernozems have the highest content of organic soil and the highest biogenicity indicators. The biogenicity index is calculated by the percentage of the number of ecological and trophic groups of microorganisms.

Key words*: soil structure, chernozem, organic part of soil, biological activity of soil.*

INTRODUCTION

Under the action of the soil-forming process, physical, chemical, physico-chemical, and biological characteristics of soils are formed, which largely determine the level of fertility of specific soils. Among them, physical indicators stand out: structural condition, soil density, solid phase density, etc.

The use of typical chernozems in conditions of deficiency of organic substances and biophilic elements in comparison with virgin analogues, according to Nosco (2006), weakens the chernozem process of soil formation and reduces soil fertility.

Even in the early works of Dokuchaev, Sibirtsev, Kostychev noted that during the plowing of virgin chernozems, the amount of humus decreases, the granular structure loosens (destroys), that is, plowing soils causes their "ploughing". Dokuchaev compared arable soils with bricks made from natural clay, and virgin (natural) chernozems were formed on clay.

Of particular importance in the life of plants is the structural state of the soil, which creates better conditions for seed germination, growth and development of plant roots, due to which the yield of crops grown on structural soils is usually high and guaranteed to be stable. Therefore, the study of the structural state of soils is constantly relevant.

In the works of Dokuchaev, Kostychev the main aspects of the role of the structure in the formation of the agronomic qualities of the soil were noted. The role of structure in soil fertility was studied in detail by Williams. Further research by Gedroits (1912; 1922), Sokolovskij (1941), Hrinchenko (1973), Medvedev (2017) and others laid the foundation for studying the physical properties of soils.

According to Nosco (2006), in particular, studied chernozems should differ from other soils by a high level of potential fertility, the most favorable structure and water regime for plants.

In the course of agricultural development and subsequent use of soils, there is a change in the water resistance of structural aggregates, the density and density of the solid phase, water permeability and general porosity, and the formation of a surface crust. This fact is confirmed by the research of Medvedev (2013; 2009; 2004), Tikhonenko (2014), Nosko (2006), Mucha (2004) and others.

It is known that the plowing of chernozems leads to a decrease in the amount of humus (increases mineralization), the supply of nutrients and exchangeable calcium. All this together determines the deterioration of the structural condition of chernozems and its physical indicators (Dehtiariov, 2011).

Microbiological activity (Geisseler, 2014) of chernozems under various phytocenoses is

highest in the upper (0-40 cm) soil layers, where soil formation processes under the influence of vegetation, leaf litter, and soil organisms occur more intensively.

Medvedev (2015) points out that the structure and density of soils are the main parameters that determine their physical properties and modes, which strongly affects the yield of agricultural plants. Mucha et al. (2006) notes that one of the leading mechanisms of the negative effect of soil degradation is a change in the structural-aggregate composition and density of the soil structure during the growing season.

Factors that lead to a significant deterioration of the agrophysical condition of soils in agronomic terms include: excessively intensive cultivation, the compacting effect of agricultural machinery, uncontrolled irrigation, violations of crop rotation. However, it is heavy equipment that causes the greatest deformations of the soil (Medvedev, 2013).

The aim of the work: to investigate the change in the structural state of chernozems in different agroecosystems.

MATERIALS AND METHODS

Two objects were chosen to solve the tasks. The first of them is the territory of "Mykhailivska virgin land" of the Ukrainian Steppe Nature Reserve (USNR) - Sumy Region. The second is the educational-scientific-production center "Experimental field" of the State Biotechnological University - Kharkiv region.

The studied area is typical for all indicators (including soil) for the Left Bank of the Forest-Steppe of Ukraine, where typical medium and heavy loam chernozems were formed on loess-like loams.

Four cuts were made within the "Mykhailivska virgin land".

Cut 1 (50.747344, 34.192909) was laid on a flat area of the local watershed within the absolute wilderness where a typical deep medium-humus (structural) medium-loam chernozem was formed on loess-like loam. Cereal and herbaceous vegetation grows here, covering 100% of the soil surface. Above-ground mass of herbs (phytomass) reaches 20 t/ha.

Cut 2 (50.748104, 34.176687) is laid within the mowed fallow. Grasses are mowed once every two years. Cut 2 is located in the flat area of the local watershed. Projective coverage of the soil surface - 100%. The association is forbaceous, thin-legged and reedy. Grasses dominate: forbs - 65%, cereals - 25%, legumes - 5%, sedges - 5%.

Cut 3 (50.750548, 34.173361) was laid next to cut 2 in the fodder crop rotation field, where zoned crops were grown for more than 120 years. The reserve of terrestrial phytomass is 9 t/ha, the saturation of crop rotation with row crops is 60%. During 1996-2019, an average of 8.7 kg of nitrogenous, 9.0 kg of phosphoric and 3.3 kg of potash mineral fertilizers and 1.7 t/ha of manure of the crop rotation area were applied to the soil per year. A typical deep, low-humus (weakly structured) medium-loam agrochernozem was formed here on loess-like loam.

Cut 4 (49.900221, 36.448754) is located on an area (0.52 ha) of fallow land that has been plowed for more than 100 years. Since 1946, the site has been overgrown with grass. Over 70 years of fallow, a grass cover was formed, which covers 100% of the soil surface. Association of grasses: forb-bluegrass. Stock of above-ground phytomass is 11-12 t/ha. Under the grasses of the fallow, a profile of typical deep, medium-humus (structural) heavy loamy chernozem on loess-like loam was formed.

The 5 cut (49.903918, 36.439602) is laid on the experimental field, where for more than 100 years zoned agricultural crops of field rotation have been grown: winter wheat, corn, barley, vetch-oats, sugar beet, sunflower, etc. Stock of above-ground phytomass in crop rotation fields is 8-9 t/ha.

The water resistance of the macrostructure was determined by the method of Savinov - dry and wet sieving (Petrenko et al., 2013).

RESULTS AND DISCUSSIONS

Structural state of the soil. After conducting analyzes of soil samples of agrochernozems and typical chernozems under different phytocenoses, results were obtained regarding the structural condition and water resistance of soils depending on humus content and biogenicity.

Depending on the type of soil-forming process, different types of structural aggregates are distinguished in soils: granular, prismatic, nut-like, blocky, etc. Chernozems are characterized by a granular structure, or lumpy-granular with a clear predominance of 1-3 mm aggregates (Table 1).

The granular structure determines the good density of the structure, soil porosity, air, heat and nutrient regimes. The best quantitative indicators are characteristic of virgin chernozems, and the worst - arable (agrogenic) soils. 70 years of fallow use improves the structural condition and almost reaches the level of completely virgin soils. The most agronomically valuable aggregates (from 0.25 to 10 mm) within the humus-accumulative horizon are quantitatively represented as follows: chernozem virgin soil - 82%, arable - 70-75%, fallow - 75-80%.

Table 1. The content of structural aggregates in typical chernozems, %

Cut number	Genetic horizon. Index, cm	Content of structural aggregates, mm, %								
		>10	10-7	7-5	5-3	3-2	2-1	1-0.5	0.5-0.25	<0.25
1	Ak 0-41	4.7	7.0	11.5	21.9	16.3	17.3	2.4	5.6	13.3
	B_1k 41-73	7.0	5.9	7.7	13.2	13.3	17.8	3.4	7.5	24.2
	B_2k 73-120	9.0	7.1	8.0	11.7	12.2	17.6	4.1	7.7	22.7
	BCk 120-160	2.7	4.3	6.1	11.1	12.8	18.4	3.5	9.1	32.1
2	A 0-35	5.5	7.0	9.1	16.1	13.5	16.6	2.5	7.5	22.2
	B_1k 35-52	1.8	4.8	6.6	13.4	13.0	20.0	3.1	9.2	28.2
	B_2k 52-85	5.9	7.5	10.6	16.8	14.8	17.6	3.3	7.1	16.6
	B_3k 85-121	4.0	6.2	7.2	13.3	13.2	18.8	3.1	8.9	25.4
	BCk 121-152	6.1	8.1	8.1	13.1	13.0	18.6	3.7	8.9	20.5
	Ck 152-189	6.5	5.9	7.5	11.7	12.4	18.4	3.7	11.1	22.9
3	A 0-23	8.1	7.7	8.1	12.3	10.5	18.0	3.1	10.9	21.4
	B_1k 23-42	3.1	6.1	7.9	15.5	16.5	21.8	3.0	9.1	17.1
	B_2k 42-64	2.6	4.5	7.9	17.7	17.7	21.8	3.5	8.1	16.2
	B_3k 64-85	4.1	6.6	7.5	12.7	14.7	21.1	2.8	9.5	21.0
	B_4k 85-111	4.3	4.6	6.8	12.0	13.8	19.6	3.4	10.4	25.2
	BCk 111-169	6.6	7.6	7.7	12.8	12.8	20.3	3.8	10.4	18.0
	Ck 169-230	5.9	8.7	8.9	14.1	12.3	18.9	4.5	12.5	14.3
4	A 0-45	20.3	19.6	17.6	19.6	10.7	8.4	1.4	1.6	0.8
	B_1k 45-72	10.7	10.7	12.8	22.7	17.9	15.6	2.2	4.3	3.1
	B_2k 72-94	9.4	9.5	9.6	19.1	16.1	19.1	3.9	7.8	5.5
	BCk 94-115	15.4	8.3	8.6	14.2	14.0	20.3	2.9	9.2	7.1
	Ck 115-153	14.3	7.7	8.7	14.6	12.6	19.6	3.5	10.4	8.6
5	A_1 0-20	12.7	8.1	7.2	9.7	10.1	24.6	6.2	11.7	9.7
	A_2 20-45	19.0	17.2	13.7	17.6	13.7	13.2	2.4	2.3	0.9
	Bk 45-73	10.7	13.4	16.9	22.8	16.5	13.0	2.0	3.0	1.7
	BCk 73-102	16.9	12.6	11.1	16.8	14.3	16.8	2.6	6.2	2.7
	Ck 102-130	17.0	12.0	10.3	17.5	13.5	16.1	2.9	6.4	4.3
LSD_{05}		2.1	1.3	1.4	1.9	1.6	2.1	0.8	1.2	2.4

In this case, let us prove that organic substances have an influence on the formation of structural aggregates. The degree of soil structure is expressed by the coefficient of structure (Table 2).

Its indicators in typical chernozems are as follows: virgin soils - 4.6, arable - 2.4-3.4, fallow - 2.6-3.8, which also distinguishes arable soils.

Water resistance of structural units. The content of water-resistant aggregates undergoes the most significant changes as a result of soil cultivation. In addition, water resistance is an important agronomic property of the soil structure, which is manifested by the ability of structural aggregates to resist the destructive action of water flow for a long time. The stability of soil aggregates, first of all, depends on the quality of humic substances, which are the main "glue" material. Therefore, in all variants, without exception, the percentage content of aggregates greater than 0.25 mm prevailed (Table 3).

Among the agronomically valuable (water-resistant) aggregates of 0.5-0.25 mm, aggregates with a size of 7 to 0.25 mm were evenly distributed along the profile on the fallow variant of the "Experimental Field".

A somewhat different situation is observed in the completely virgin and fallow chernozem of the "Mykhailivska virgin land", where aggregates of 2-1 mm were dominant, but also with insignificant fluctuations in the profile. On arable land variants, the content of the 0.5-0.25 mm fraction is the largest, and water-resistant aggregates are unevenly distributed.

Table 2. Indicators of the structural state of typical chernozems

Cut number	Genetic horizon. Index, cm	Coefficient of structure	Σ aggregates 0.25-10 mm	Assessment of structural condition
1	Ak 0-41	4.5	82	excellent
	B_1k 41-73	2.2	69	good
	B_2k 73-120	2.1	68	good
	BCk 120-160	1.9	65	good
2	A 0-35	2.6	72	good
	B_1k 35-52	2.3	70	good
	B_2k 52-85	3.5	78	good
	B_3k 85-121	2.4	71	good
	BCk 121-152	2.8	73	good
	Ck 152-189	2.4	72	good
3	A 0-23	2.4	70	good
	B_1k 23-42	4.0	80	good
	B_2k 42-64	4.4	81	excellent
	B_3k 64-85	3.0	75	good
	B_4k 85-111	2.4	71	good
	BCk 111-169	3.0	70	good
	Ck 169-230	4.0	80	good
4	A 0-45	23.8	79	good
	B_1k 45-72	12.5	86	excellent
	B_2k 72-94	10.3	85	excellent
	BCk 94-115	6.9	78	good
	Ck 115-153	8.6	77	good
5	A_1 0-20	12.6	78	good
	A_2 20-45	26.7	79	good
	Bk 45-73	11.5	88	excellent
	BCk 73-102	8.9	80	excellent
	Ck 102-130	12.8	79	good

Table 3. The content of water-resistant aggregates in typical chernozems, %

Cut number	Genetic horizon. Index, cm	Content of waterproof aggregates, mm, %						
		7-5	3-5	3-2	2-1	1-0.5	0.5-0.25	<0.25
1	Ak 0-41	11.2	14.8	14.0	15.4	8.8	8.5	27.3
	B_1k 41-73	11.1	8.0	7.9	14.4	6.8	9.3	42.5
	B_2k 73-120	8.5	5.9	6.8	10.9	7.4	10.2	50.2
	BCk 120-160	1.9	2.5	4.1	6.8	6.6	11.3	66.8
2	A 0-35	10.6	13.5	11.4	17.0	6.4	9.1	32.0
	B_1k 35-52	11.1	8.3	11.9	14.8	8.1	10.3	35.5
	B_2k 52-85	11.3	10.2	11.6	14.5	11.5	10.6	30.4
	B_3k 85-121	3.4	5.2	8.1	12.8	9.2	13.5	47.7
	BCk 121-152	3.2	3.2	4.7	10.0	7.2	14.3	57.4
	Ck 152-189	0.5	0.8	0.6	1.0	2.5	9.2	85.5
3	A 0-23	1.6	2.4	2.6	4.5	9.5	24.6	54.8
	B_1k 23-42	0.5	2.4	6.0	15.2	12.7	18.6	44.5
	B_2k 42-64	1.1	6.7	12.2	17.8	9.6	13.5	39.0
	B_3k 64-85	3.0	7.2	8.4	15.1	8.3	10.8	47.1
	B_4k 85-111	0.8	4.5	6.1	11.3	7.4	11.9	58.0
	BCk 111-169	4.8	2.1	3.2	6.6	6.1	11.5	65.6
	Ck 169-230	0.0	0.0	0.4	0.2	2.9	7.3	89.2
4	A 0-45	1.5	4.8	9.0	23.6	11.1	23.6	26.4
	B_1k 45-72	0.0	0.9	3.3	15.3	13.5	29.8	37.2
	B_2k 72-94	0.0	0.6	3.0	12.4	13.0	30.9	40.0
	BCk 94-115	0.4	0.7	1.8	6.6	8.6	24.3	57.6
	Ck 115-153	0.0	0.2	0.5	2.6	6.5	28.8	61.4
5	A_1 0-20	0.5	2.2	6.1	28.2	13.9	21.4	27.8
	A_2 20-45	0.0	0.3	1.3	8.5	14.6	39.5	35.7
	Bk 45-73	0.0	0.3	1.0	6.9	12.0	34.2	45.6
	BCk 73-102	0.0	0.4	1.6	7.8	11.8	32.4	45.9
	Ck 102-130	0.0	0.6	1.8	10.4	12.4	28.3	46.4
LSD_{05}		1.1	0.5	0.9	1.2	1.1	0.7	-

The coefficient of water resistance of virgin soils is about 0.90 in the upper humus-accumulative horizon and gradually decreases with the depth of the profile (Table 4).

The fallow variants are characterized by even a slight increase in the coefficient of water resistance - 0.93-0.94, and arable soils, on the contrary, have a decrease from 0.93 to 0.64. Evaluation of the studied soils by the sum of water-resistant aggregates greater than 0.25 mm shows a decrease in their number down the profile (Table 4).

The best water resistance is present in the variants with the introduction of a fallow regime (excellent rating), and also, naturally, in the variant with completely virgin soil due to the presence of a significant number of aggregates of agronomically valuable sizes of structural elements (the sum of water-resistant aggregates is more than 0.25 mm). Arable soils have a good assessment of water resistance.

Table 4. Indicators of water resistance of typical chernozems

Cut number	Genetic horizon. Index, cm	Coefficient of water resistance	Σ aggregates > 0.25	Assessment of water resistance
1	Ak 0-41	0.89	73	excellent
	B_1k 41-73	0.84	58	good
	B_2k 73-120	0.73	50	good
	BCk 120-160	0.51	33	satisfactory
2	A 0-35	0.94	68	excellent
	B_1k 35-52	0.92	65	excellent
	B_2k 52-85	0.90	70	excellent
	B_3k 85-121	0.74	52	good
	BCk 121-152	0.58	43	good
	Ck 152-189	0.21	15	unsatisfactory
3	A 0-23	0.64	45	good
	B_1k 23-42	0.69	56	good
	B_2k 42-64	0.75	61	excellent
	B_3k 64-85	0.71	53	good
	B_4k 85-111	0.60	42	good
	BCk 111-169	0.46	34	satisfactory
	Ck 169-230	0.14	11	unsatisfactory
4	A 0-45	0.93	74	excellent
	B_1k 45-72	0.73	63	excellent
	B_2k 72-94	0.70	60	good
	BCk 94-115	0.55	42	good
	Ck 115-153	0.50	39	satisfactory
5	A_1 0-20	0.93	72	excellent
	A_2 20-45	0.80	64	excellent
	Bk 45-73	0.62	54	good
	BCk 73-102	0.67	54	good
	Ck 102-130	0.68	54	good

The highest percentage of humus is characteristic of virgin chernozems - up to 10.1% (humus reserve - 190 t/ha), fallows and chernozems under the forest belt - up to 7.5-8.5% (172-181 t/ha), and arable soils have a maximum of up to 5-6% (138-139 t/ha).

Arable (agrogenic) chernozems have the highest biogenicity - in the upper genetic horizon - 6.88, and 7.07 million colony-forming embryos in 1 g of completely dry soil on the “Experimental field” and “Mykhailivska virgin land” arable land variants. Post-agrogenic use leads to a significant decrease in biogenicity under all the studied variants. At the same time, the values of the variants of fallow and absolute virgin land fluctuate insignificantly within the range of 5.63-5.91 million colony-forming embryos in 1 g of completely dry soil. The lowest biogenicity is observed in chernozems of post-agrogenic use.

As for the correlation between the structure factor and the humus content, we have a weak direct relationship - 0.23. Speaking of the correlation between the water resistance coefficient and the content of humic substances, here we have a strong direct relationship - 0.81. Therefore, it is the humic substances that act as a binding material under the mechanical action of water on the soil and prevent structural aggregates from collapsing.

CONCLUSIONS

Humus content and biogenicity play an important role in forming the structure of soils in general and chernozems typical under various phytocenoses in particular. Thus, the peptizing effect is caused by the presence of ammonium ions, and calcium, on the contrary, acts as a coagulant. The humus-accumulative process of soil formation determines the dominant role of exchangeable calcium, which, together with other factors, contributes to the good structure of soils. In arable soils (agrochernozems), the amount of exchangeable calcium decreases, at the same time, cultivation leads to deterioration of the structural condition of the soils.

Thus, fallow and virgin chernozems typically have an excellent structural condition and have the highest water resistance. Arable soils (agrochernozems) are characterized by structural deterioration.

According to the indicators of the structural state, the studied soils can be divided into three groups: the first - virgin soils, with the best indicators of structure and water resistance; the second - fallow, with values close to virgin; the third - arable soils (agrochernozems), with the smallest and significantly different structure values from the previous variants.

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