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Structural state of chernozem after long-term post-agrogenic transformation

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The purpose. To determine the main laws of transformation and regulatory parameters of the structural state change of chernozems of the forest-steppe zone in conditions of long-term post-agrogenic transformation according to the results of dry sieving of soil samples and statistical analysis of the data using the method of principal components, factor and non-parametric analysis. **Methods.** Laboratory analytical, experimental field, statistical. **Results.** The performed statistical processing of results of the analysis of dry sieving of the structure of chernozems in the long-term post-agrogenic state demonstrates the promise of using factor, cluster and non-parametric analysis methods. An important role in the restoration of the structure of chernozems is played by a combination of structural units 3.0–0.5 mm in size, with which the additional density in the humus horizon is inversely proportional, and with the humus content, it is directly proportional. The carried out clustering indicates that the content of the presented chernozems in the state of virgin soil and long-term deposits is the separated and not similar state of soil objects. But there is a general pattern of formation of a set of structural units of 3.0-0.5 mm similar to chernozems in the state of virgin soil, which content exceeds 40-50% of the content of parts in the agronomically valuable interval. **Conclusions.** After withdrawal from agricultural circulation, chernozems of agrocenoses enter into a complex process of self-healing, which goes in the direction of the virgin zone type. During post-agrogenic evolution, the accumulation of total humus occurs and the structural organization of the arable layer is gradually restored. In the first 20-25 years, there is a noticeable increase in the share of macroaggregates, including agronomically valuable ones, and the corresponding decrease in the number of microaggregates, which indicates an improvement in agronomic properties of shifted chernozems. In accordance with the number of agronomically valuable aggregates, all chernozems of the represented fallow series are characterized as excellent, and the dynamics of the growth of the structural coefficient increases with age towards virgin soil.

Key words: *virgin soil, Forest-steppe zone, dry sieving, structural units, humus horizon, zonal type.*

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Chernozems have historically been an interesting object of study in genetic soil science, having a powerful humus horizon with grain-fine-grained structure; made them the standard of fertility [1]. The origin, formation, stability of structural entities and, conversely, the processes of loss of aggregate structure, its degradation are processes that directly affect the complex fundamental physicochemical and biological processes in the black earth and, at the same time, are actual and practical. The structure of black earths influences the fundamental carbon cycle [2], fertility, environmental status and humus regimes in black earths [3-11]. The structural composition of black soil is the result of the joint action of various physical, chemical, biological and physical processes of soil formation and is one of the main qualitative features of black soil [12]. The extent to which large and small structural entities are represented depends on all the fundamental properties of the black earth, all the basic processes that determine its internal life and functions in the biosphere [13-15]. Black earths, in which macroaggregates predominate, tend to contain more organic and nutrients, are less susceptible to erosion and create optimal physical regimes [13-16].

Throwing of arable black soils into the fallow is accompanied by the removal of agricultural load and triggers a complex process of reproduction, both zonal vegetation and soil fertility – fallow succession [17], which is accompanied by a relatively rapid differentiation of humus horizon, forming the surface of the turf - 19]. The subsoil is gradually transformed in the direction of the virgin background black soil corresponding to the depth of the horizon [20-25].

The simplest method of quantifying the structure is to sift through air-dry soil through a set of sieves of different sizes. In practice, sieves with a size of 0.25 are usually used; 0.5; 1.0; 2.0; 3.0; 4.0; 5,0; 7.0; 10.0 mm, obtaining the distribution of structural units in size: from particles <0.25 mm to tubercles> 10 mm

[7, 12, 23]. The result is 9 values that characterize the soil structure in the air-dry state. However, the accepted procedures for processing the results of the analysis are usually aimed at reducing all the data obtained to a limited number of indicators. The interpretation is complicated by the fact that, in different soil and climatic conditions, the content of agronomically valuable aggregates is used for quantitative characterization of the structure, and different size limits of this fraction are given in different sources: the majority refers to the agronomically valuable aggregates of the fraction 7-0,5mm, or 10-0.25 mm [4, 9, 20-22]. In addition, the average size of aggregates, such as their weighted average diameter and geometric mean diameter, are used. According to the determined methodological approach, only one value is obtained from a sufficiently large array of data (size distribution), which complicates the detailed characterization of the soil structure.

The scientific novelty of the conducted research lies in the fact that using modern methods of statistical analysis of data of dry sifting of soil the influence of each group of structural individuals within the agronomically valuable interval on the change of the density of structure in the humus horizon of black earth is determined, and also the fundamental value of structural units 0-0. , 5mm, which have a decisive influence on the agrophysical and humus state of the chernozem in the post-terrogeneous state.

Relevance of research. At present, when multidimensional statistical analysis methods have become available with the development of computing, the unreasonable collapse of the dry sifting data set seems irrational. Existing modern statistical methods and approaches allow to maximize the amount of data received with minimal loss of information. One of the most common approaches is Principal component analysis (PCA), cluster analysis and nonparametric statistics.

The aim of the study: to identify the basic patterns of transformation and normative parameters of the change of the structural state of chernozems of the Forest-Steppe zone in the conditions of long-term post-tropical transformation by the results of dry sieving of soil samples and statistical analysis of the obtained data using the principal component method, factor and nonparametric analyzes.

Object of study: processes of redistribution of structural individuals and formation of normative parameters of the structure of chernozems during long-term post-genogenic transformation.

Subject of study: analysis of the constituents of the structural state of black earths by means of factor, cluster analysis and methods of nonparametric statistics.

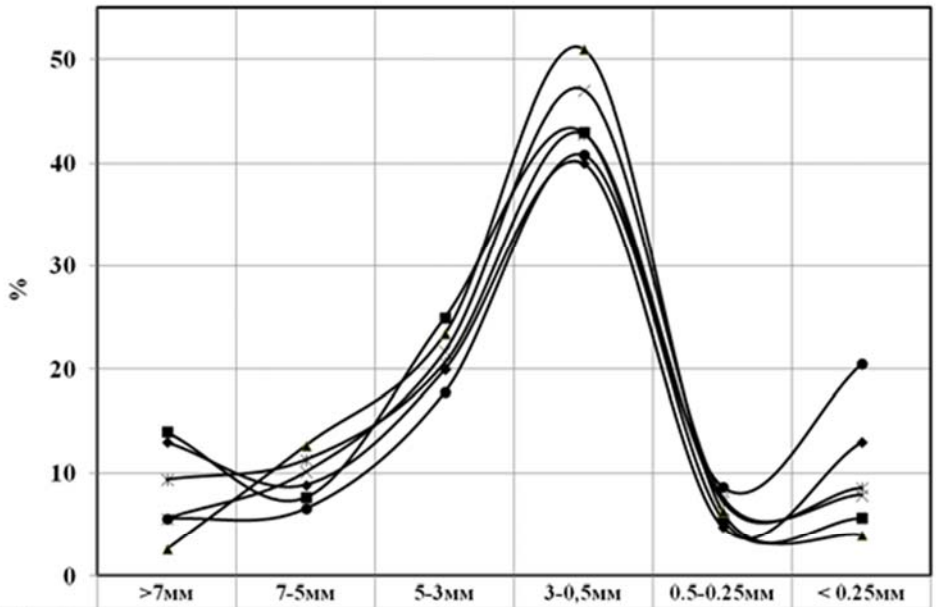
Ground conditions for research. The study of long-term post-threatening influence on the restoration of the structural state of the typical black earths was carried out in the Forest-steppe Left Bank Physical and Geographical Province in the southern part of Vorsklo-Sulsky and Sredneprovsko-Seimsky districts. The soil cover within the southern part is represented by chernozems typical humus (5.55–5.65%). Perologs of 15 and 150 years in the Middle Dnieper-Sejm agro-soil district. The deposits are laid in the Drabiv Agro-Soil Area of the Forest-Steppe Zone of the Left-Bank Lowland Province, northern sub-province on the black earths of typical low-humus light-loamy silt-dusty. He is over 55 and 45 years old. For the statistical analysis of the constituents of the structural state, the literary data obtained at the Rogan hospital of the Kharkov National Agrarian University. V.V.Dokuchaev and the branch of the Ukrainian Steppe Nature Reserve – "Mykhailivka virgin", which are located within the Central Russian province of the Forest-Steppe of Ukraine. The soil cover of the reserve is mainly composed of chernozems of typical mid-loam, which lie on watershed plateaus and slightly sloping slopes. The structural condition of an absolutely virgin section of the reserve, a 42-year-old folded breed and a maple-tree forest area was analyzed [29]. The steppe stratum of 1882 with naturally preserved biocenosis has been selected as the standard of structural status [30].

Analysis of the structural composition was carried out in the 0-40 cm soil layer. Physical parameters were studied: density of soil solid phase (pycnometric according to DSTU 4745: 2007); density of soil folding (according to DSTU ISO 11272-2001); dry sieving by MI Savvinov according to DSTU 4744: 2007) [31]. The structural state was studied in conjunction with the determination of the density of the structure. The content of the total humus – according to IV Tyurin in modification MV Simakov (according to DSTU 4289: 2004).

Interpretation of results. The chernozems were classified by cluster analysis and the principal component method for different retention times in the fracture state and the virgin soil, which revealed the main constituents of the data sets of groups of structural sizes of different sizes obtained by dry sieving of air samples. STATISTICA-10 was used to construct similarity dendrograms, for the principal component method and for nonparametric soil structure estimation.

Research results. The virgin and translucent chernozems of the left-bank forest-steppe are characterized by a granular-fine-lumpy structure. Structural analysis data (dry sifting) indicate a significant bridge of agronomically valuable structural units of size 10 (7) -0.25 mm, the number of which in the humus horizon ranges from 81-94%, but most of them account for the particle size from 3 to 0.5 mm (40-53%) (Fig. 1). Due to the low content of agronomically valuable structural units with size> 10 (7) mm (2-14%) and <0.25 mm (4-13%), the structural coefficient reaches a considerable value and varies on average from 6.4 – 8.6.

The investigated subtypes of virgin-chernozem soils, possessing large reserves of organic matter (4.96-9.55%), powerful humus horizon and heavy and medium granulometric composition, have high microaggregation, agronomically valuable water-resistant structure and, as a consequence, are optimal and stable. indicators of basic physical properties. First of all, they are characterized by low density of structure (0.95-1.12 g / cm3), high overall porosity, optimum ratio of the air widths to the wells occupied by different forms of soil moisture, which is ensured by the formation of structural features 3.0-0 in size, 5 mm 50%, and on the shifting chernozem – at the level of 40-48% (Fig. 1).



	>7мм	7-5мм	5-3мм	3-0,5мм	0.5-0.25мм	< 0.25мм
Переліг-40 років (Драбово)	13	8,9	20	40	4,8	13
Переліг-150 років (Карлівка)	14	7,7	25	43	5,6	5,68
Переліг з 1882 року.	2,6	12,7	23,4	51	6,3	4
Заповідний степ	5,6	10,1	21,7	47	7,7	7,9
Переліг-54 роки	9,4	11,3	20,6	42,8	7,3	8,6
Лісосмуга-54 роки	5,6	6,6	17,8	40,8	8,7	20,5

Fig. 1. The distribution of structural features (0-40 cm) with the maintenance of chernozems in the state of virgin soil and long-term deposits in the Left Bank Forest Steppe of Ukraine

Statistical analysis showed that the factor load of individual groups of structural entities by the main factor (F1) by the level of strong inverse correlation is characteristic of the individual sizes 7-5 mm, 3-0.5 mm, and 7-0.5 mm (R = -0, 79-0,98 ± 0,03; R2 = 0,62-0,96), and individuals of size 5-3 mm are bound by F2 at the level of inverse strong correlation (R = -0,78 ± 0,03; R2 = 0.61). The humus content of the black soil was related to F2 at the level of inversely strong correlation as well as Kstr: R = -0,83 and R = -0,92 respectively. The contents of the fractions of the invaluable fraction (sizes> 7 mm and> 7 mm + <0.25 mm) by factor F1 were pegged at the level of direct strong correlation (R = + 0.75-0.98 ± 0.02), as and structure density. For factor F2, the individual sizes of 0.5-0.25 mm and <0.25 mm were related at the level of direct strong correlation, but were less significant in the formation of the systematic structure of the structural state of the chernozems while being maintained in the fracture and virgin state. Factor F1 accounted for 63% of the total dispersion of the constituents, and for F2 – 27%.

Parametrization of the model of the structural state of sediments and virgin chernozem showed that the individual size of 7-0.5 mm was on average 81.8%, and the amplitude span ranged from 73.7% to

87.7%. The typical span was 73.9-86.5%, and the median content of the individual content was 81.7% and gravitated to the upper standard value. Structural separations in the size of 3-0.5 mm from the sum of 7-0.5 mm in all parameters was 53-54%, and therefore the regularity of statistical interpretation of the specified group of individuals is similar to the general in the group of individuals 7-0.5 mm (Table).

Separations of 5-3 mm in size on average and on the median contained 21.2-21.4%, which is 2 times less than the contents of the units of size 3-0,5 mm. The typed span was 20.0-23.4%, and the amplitude span coincided with the normalized value of 10%: 17.8-25.0%.

Statistical parameters of the structural composition of chernozems of typical long-term deposits and virgin soil

Ingredients Indexes Soil structure	Content of structural units,%:								
	average	behind the median	Minimum, min.	Maximum, max.	*$L_{0,25}$	*$L_{0,75}$	**$L_{10,0}$	$L_{90,0}$	***Coef.Var., %
			The amplitude this range: Δ=max-min		Normalized scope: with 50% probability $\Delta=L_{0,75-0,25}$		with a 10% probability		
7-5mm	9,55	9,50	6,60	12,7	7,70	11,3	6,60	12,7	23,8
5-3mm	21,4	21,2	17,8	25,0	20,0	23,4	17,8	25,0	11,9
3-0,5mm	44,1	42,9	40,0	51,0	40,8	47,0	40,0	51,0	9,44
7-0,5mm	81,8	81,7	73,7	93,4	73,9	86,5	73,7	93,4	9,23
<0,25mm	9,95	8,25	4,00	20,5	5,68	13,0	4,00	20,5	60,3
>7mm+< 0,25mm	18,3	18,7	6,60	26,3	13,5	26,1	6,60	26,3	41,3
$K_{стр}$	5,83	4,38	2,80	14,2	2,83	6,41	2,80	14,2	73,61
g / cm^3	1,04	1,05	0,95	1,12	1,01	1,09	0,95	1,12	5,77
humus,%	7,26	7,21	4,96	9,55	5,86	8,75	4,96	9,55	23,6

*L0,25 – lower quantile; L0,75-upper quantum; **L0,10 – lower decile; L0.90-top decile. ***Coef.Var.,% Is the coefficient of variation.

The average and median contents of structural units 7-5 mm in size were 2.2-2.3 times smaller than those of 5-3 mm and made 9.5-9.6% in the amplitude range from 6.6% to 12 , 7% and the standardized range of 7.70-11.3%, at 10% of the significance level of 6.60-12.7%. As the size of the structural individual groups grows, the coefficient of variation of their content increases: 9.23% (7-0.5 mm), 9.44% (3-0.5 mm), 11.9% (5-3 mm), 23.8% (7-5 mm).

Agronomically invaluable structural individuals of> 7 mm in size with a median and median value contained 7.5-8.4% with an amplitude range of 2.60-13.6%. Typical swing was 5.6-13.3%, and at 10% level of value 2.6-13.6%. The coefficient of variation reached 53.9%. On the whole, agronomically invaluable individuals (> 7 mm + <0.25 mm) in the mean and median values contained 18.3-18.6% with an amplitude range from 6.60% to 26.3% and normalized – 13.5- 26.1%. The content variation coefficient of this aggregate group was 41.3%.

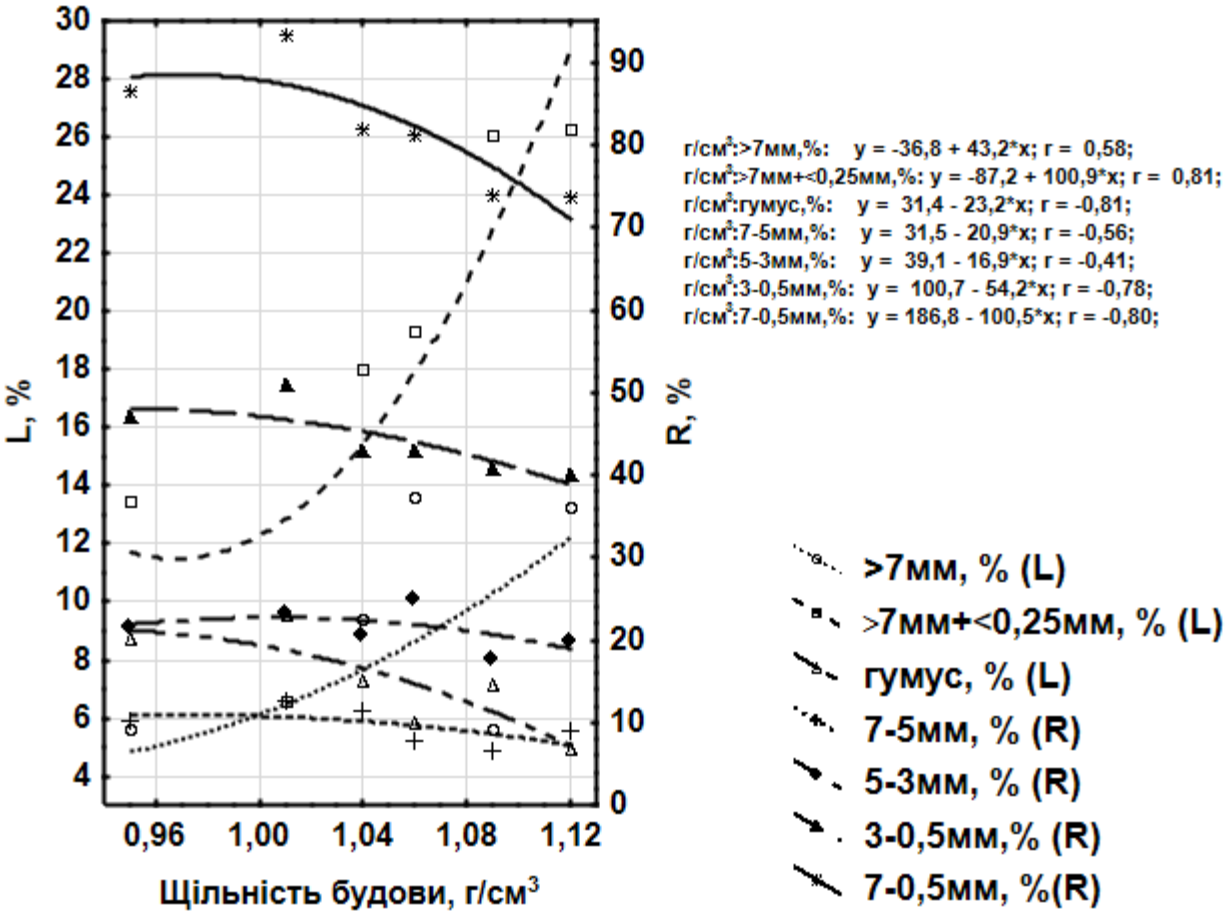


Fig. 2. Dependence of density of soil structure on in the city of structural distinctions of different size while holding the chernozem typical in the state of fold and virgin soil

Formed statistical model of the structural state of black earths in the state of deposits and virgin soil corresponds to the average humus content at the level of 7.21-7.26% with an amplitude range of 4.96-9.55% and a typical content of 5.86-8.75%. The coefficient of variation of humus content was 23.7%. The mean and median value of the structure density was 1.04-1.05 g/cm^3 with an amplitude range from 0.25 g/cm^3 to 1.12 g/cm^3 and at a typical structure density interval of 1.01-1.09 g/cm^3. The coefficient of variation of the density of the structure was 5.77%.

Further calculations showed that an inverse correlation relationship (R = -0.58-0.80 ± 0.02; R2 = 0.35-0.64) was found between the contents of the most valuable structural entities and the density of the structure, the value of which is greatest. the extent was with the fraction of structural separate 3-0.5 mm (R = -0.80 ± 0.03; R2 = 0.64).

There was a direct correlation between the content of agronomically invaluable individuals and the density of the structure (R = + 0.59-0.80 ± 0.02; R2 = 0.35-0.64). The relationship between the structure density and the humus content was at the level of inverse strong correlation (R = -0.81 ± 0.03; R2 = 0,66), and the unit density of black earth density accounted for 0.74% increase in humus content.

It was found that a direct correlation was found between the content of humus and structural units of size 0.5-3 mm and 0.5-7 mm at the level of strong correlation (R = 0.83-0.88 ± 0.02; R2 = 0.68-0.76), and per unit increase in humus content (0.01%) accounts for 0.075 and 0.066% increase in the content of fractions of groups of structural individuals (Fig. 2). It has been found that per unit growth of the content of individual sizes 3-0.5 mm accounts for 0.01 g/cm^3 of black earth decomposition. Considering that a close correlation relationship is found between the content of 3-0.5 mm and 7-0.5 mm individuals (R = 0.97 ± 0.03; R2 = 0.95), and per unit growth of individual content 7-0.5 mm account for 0.47% of growth of the individual 3-0.5 mm it can be stated that these groups of individual determine the agrophysical state of the chernozems in the state of fallow and virgin soil, and the growth or decrease of the content of agronomically valuable individuals by the size of 7-0.5 mm determines the increase or decrease of the structure density by 0.0065 g/cm^3.

The results of clustering of chernozems in the state of long-term fracture and virgin soil by the method of cluster analysis of the distribution of structural distinctions in them are shown in the dendrogram (Fig. 3). Clustering by the degree of similarity of individual groups of components of the soil structure of chernozem in the state of virgin soil and long-term deposits shows a measure of similarity regardless of the soil objects themselves. Separation of 3-0.5 mm and 7-0.5 mm individual sizes enhances the overall pattern.

It is revealed that the degree of similarity between individual groups of structural individuals is low, which indicates their different qualitative value in the sum, both in agronomically valuable structure and in the aggregate. The degree of similarity to the level of 60-65% and almost to 100% similarity testifies to the role not of individual fractions of structural individuals, but their grouping into more general collections, which form the functional relationships with the density of structure and humus content and determine the qualitative level of soil structure of the black soil in the state of fracture and long-term retention of the fracture in the general pattern (Fig. 3A).

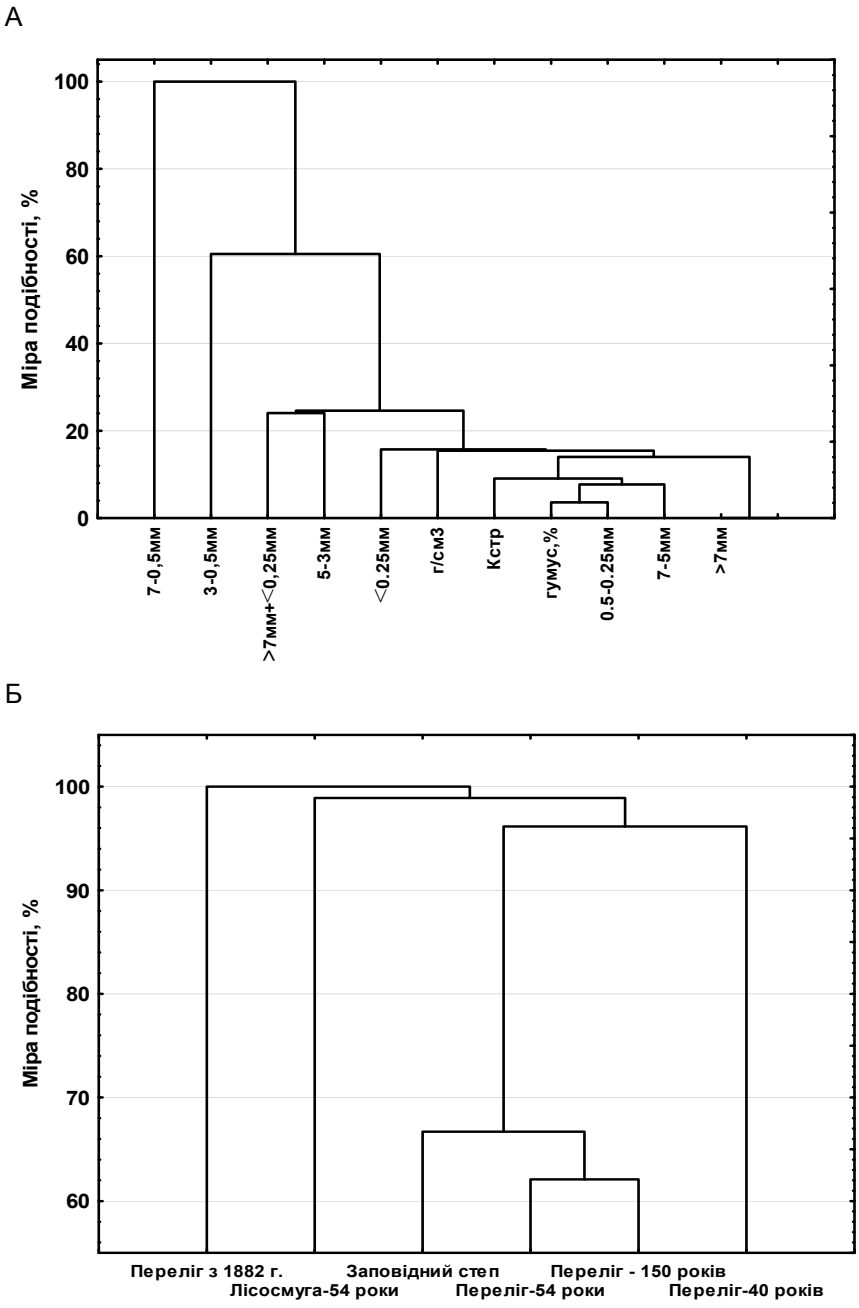


Fig. 3. Measure of similarity (%) of hierarchical grouping by the results of analysis of dry sieving of soil structure (A) of chernozems in the condition of virgin soil and long-term fallow lands (B)

In general, the similarity levels between the soil objects of the black earth in the virgin state and the long-term deposits are presented in Figs. 3Б. The most dissimilarities are: the 54-year milestone and the 150-year milestone - a similarity rate of 60-65%, and with the protected steppe – 65-67%. The overgrowth since 1882 and the overgrowth of 40 years and the forest belt of 54 years are separated in soil objects with a degree of similarity at the level of 100% with the maximum distance of the soil objects themselves.

Conclusions

The statistical analysis of the results of the analysis of the dry sieving of the structure of chernozems in the long-term post-rogenic state demonstrates the prospect of using factor, cluster and nonparametric methods of analysis. An important role in the restoration of the structure of black earths is played by a set of structural individuals of 3.0-0.5 mm in size, with which the density of the structure in the humus horizon is reversed, and with the content of the humus – a direct correlation.

The conducted clustering shows that the retention of the represented chernozems in the state of virgin soil and long-term deposits is a separate and not similar state of soil objects, but there is a general pattern of formation of a set of structural individuals of 3.0-0.5 mm in size, as in chernozem in the condition of virgin soil, the content of which exceeds 40-50% of the content of the individual in an agronomically valuable interval.

Agro-Cenozoic chernozems, after being withdrawn from agricultural circulation, enter into a complex process of self-recovery, which goes in the direction of the virgin zonal type. During post-genogenic evolution, the content of the total humus is accumulated and the structural organization of the former arable layer is gradually restored. In the first 20-25 years, there is a noticeable increase in the number of macroaggregates, including agronomically valuable, and a corresponding decrease in the number of microaggregates, which indicates an improvement in the agronomic properties of the translucent chernozem. All the chernozems of the present sedimentary series according to the number of agronomically valuable aggregates are characterized as excellent (according to VV Medvedev's classification), and the dynamics of growth of the coefficient of structurality increases with the age of the fracture towards the whole.

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