UDC 631.43

MICROAGROGENESIS OF CHERNOZEM IN AGROCENOSIS

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Received on March 09, 2017

The aim of the study was to provide scientific and theoretical substantiation for the process of microaggregation of typical chernozem via the simulation of natural processes of soil formation under the effect of systematic application of soil-protecting technologies of crop cultivation with surface packing of root and after-harvest remains, humus, and mineral fertilizers in agrocenoses of the Left-Bank Forest-Steppe of Ukraine. **Methods**. Laboratory-analytical, experimental field, statistical. **Results.** During tillage (for over 75 years) the number of free and friable-linked aggregates in the 0–40-cm chernozem layer decreased down to 17–20 %, and on the background of organic-mineral system of fertilization (15 t/ha of humus + $N_{80}P_{75}K_{60}$) there was an increase in the content of the mentioned groups of microaggregates up to 20–25 %. The systematic implementation of soil protective technologies promoted the increase in the content of free and friable-linked microaggregates up to 29–32 %. During tillage, the coefficient of saturation with humus for physical clay (PC) decreased 1.3–1.4 times compared to the grassland. The value of PC saturation during the soil protective tillage was optimal, as humus was neither accumulated in the form of free humates, nor stored like "fat" in animal organisms.aAnd there was no blocking of nutrients with free humates. Humus acts as a connective tissue, promoting the improved water-resistance of chernozem structure on the micro- and macroaggregate levels. The ability of chernozems to have aggregation was determined by the dispersion factor (DF), which was 12–14 % during tillage without introducing any fertilizers, and 10 % – with the introduction of fertilizers, which testified to a weak degree of microaggregation. With minimal tillage on the background of the organo-mineral system of fertilization, DF = = 6–7 %, and by the end of rotation it decreased down to 3-5 %. **Conclusions.** Enhanced microaggregation in soil protective technologies is explained by the fact that detritus and newly formed humic substances enhance their role in the formation of organo-mineral complexes in case of optimization of hydrothermal conditions in the seasonal cycle and decreased tempo of humus mineralization. The correlation coefficient between the number of microaggregates, sized 0.01–0.25 mm and the content of peptized humic substances during tillage was as follows: R = +0.48±0.01, and for soil protective technologies it was: R = (+0.70–0.75) ± 0.01. The increase in microaggregation in conditions of soil protective tillage occurred in the direction of wild land analogs and fallow, which testified to the simulation of the natural process of typical chernozem microaggregation in the agrocenoses of the Left-Bank Forest-Steppe of Ukraine.

Keywords: microaggregates, agrogenesis, chernozem, humus, soil tillage.

DOI: 10.15407/agrisp4.01.028

INTRODUCTION

The estimation of chernozem agrogenesis should include the consideration of both granulometric and microaggregate conditions, whereas the availability of data about chernozem microstructure allows characterizing the macrostructural condition [1–6]. The theoretical fundamentals of soil microstructure formation were studied by Kachynsky [7, 8], Hodlin [9–12], Voronin [13, 14], Medvedev [15, 16], Bulyhin [17–20] who came to the conclusion that the relevance of soil microstructure was not limited to the sizes of microaggregates. A considerable role in soil fertility is played by the material, used to form microstructures. There are reverse processes in soils and soil-forming layers: on the one hand, these are processes of forming organic and mineral disperse particles, on the other – the processes of aggregation of elements with the formation of soil units – microaggregates of different sizes and forms with different properties. The main ways of forming microaggregates out of macroaggregates are known [13, 14, 22]:

- mechanic fragmentation of soil during tillage;
- microbiological destruction of humic substances, gluing particles among themselves;
- physical and chemical changes in the soil under the effect of applying agrochemical means.

The studies of Medvedev [15, 24] established that the systematic tillage was accompanied with statistically proven increase in the total and summarized active surface of chernozem, though he did not succeed in revealing the reasons of the impact of tillage on surface properties. It may be related to the specificities of transforming the fraction of humic acids during intensive tillage, which changed surface characteristics of chernozems. The number of microaggregation forms of humus decreased in arable soils compared to wild land, whereas that of macroaggregation forms increased.

Intense tillage of chernozem led to high mobility (reaction ability) of the organic matter. The increase in the mobility of humus deteriorated the water resistance of aggregates of different sizes, and its reduction might increase the microaggregation property of tilled chernozem considerably (by 10–20 % in the yield of aggregates, sized > 0.01 mm). Water resistance of microaggregates was generally determined by the content of proper humic substances, the removal of which in wild land and arable land led to sharp enrichment (up to 90–95 %) with microaggregates, sized 0.25–0.01 mm [25–28]. The dehumification of chernozems triggered the increase in degradation processes, which was testified by the works of Medvedev [23, 24], Bulyhin [21], and the studies of foreign authors [29–36].

The introduction of increased norms of complete mineral fertilizers or separate nitrogen, potassium, and phosphorus fertilizers did not change the number and ratio of particles and microaggregates. The introduction of organic fertilizers in the dose of 70 t/ha of humus promoted the increase in microaggregation. It goes beyond any doubt that soil tillage is a powerful way of creating optimal soil conditions for cultivated plants. However, the limitation of direct positive impact of tillage is known equally well [15, 17, 25].

The previous study [28] was dedicated to the investigation of the action of different systems of tillage and fertilization of chernozem on its microaggregation properties during the crop rotation in the variants without any introduction of mineral or organic fertilizers, and in variants with different doses of mineral fertilizers on the background of humus in conditions of Left-Bank Forest-Steppe of Ukraine, on typical medium and low humus light loamy and light clay-loamy chernozem.

The aim of the study was to provide scientific and theoretical substantiation for the process of microaggregation of typical chernozem via the simulation of natural processes of soil formation under the effect of systematic application of soil-protecting technologies of crop cultivation with surface packing of root and after-harvest remains, humus, and mineral fertilizers in agrocenoses of the Left-Bank Forest-Steppe of Ukraine.

MATERIALS AND METHODS

The processes and regularities of microaggregation of typical chernozem in agrocenoses of different crop rotations at long-term action of soil protective technologies of crop cultivation in the Left-Bank Forest-Steppe of Ukraine were studied. The indices of the microaggregate, structural-aggregate and humus conditions were analyzed for different ways of tillage and fertilization of chernozem. The experiments were conducted at three mutually related levels: experimental, theoretical, and descriptive-generalizing. The first level envisaged long-term field stationary experiments. The second level included the elaboration of theoretical fundamentals of the structure formation of microaggregates and restoration of natural processes of soil formation of chernozem in agrocenoses. The descriptive-generalizing level was used to analyze the weather-climatic conditions as well as the results and conclusions of other authors to compare them against the data of our research.

Long-term impact of zero tillage on the process of microaggregation of typical chernozem in the agrocenoses of the Forest-Steppe Left-Bank physical-geographical province of Ukraine was studied in Vorskla-Sula and Middle Dnieper-Seym districts. In 1990-1996, the studies were conducted in the southern part of Vorskla-Sula district. Soil surface in the southern part of the Poltava region is presented with typical chernozem

(> 50 %) which is of medium humus content (5.55–5.65 %). According to the content of physical clay (PC) and physical sand (PS) chernozem may be considered to be light clay: PC = 62.9–64 %; PS = 35–37.1 %. Similar technological indices of granulometric condition are notable for typical chernozem of the southern-eastern part of Poltava region and almost the whole territory of the Kharkiv region.

From 2001 till 2014, the experiments were conducted in Middle Dnieper-Seym agrosoil district, which covers the lands of Kyiv, Poltava, Sumy, Chernihiv, and Cherkasy regions. The experiment was performed in the Drabiv agrosoil district of the Forest-Steppe Left-Bank lowland province, northern subprovince, on typical low humus light loamy clay-silt chernozem. The structuredness index (SI) was 25–38 %. The PC:PS ratio was 1.76–2.25 which was 3.2 times higher compared to typical medium-humus light loamy chernozem. The factor of potential aggregation (FPA): FPA = 0.25–0.27 which was 2.78–2.96 times lower compared to typical medium-humic light loamy ch*ntinuous Long-term agronomic experiment No.1.* The study was conducted in 1985-1ntinuous long-term agronomic multifactor experiment of the Department of soil science and soil protection of the National University of Life and Environmental Sciences of Ukraine in the following chain (sugar beet–green peas–winter wheat–corn for grain–corn for silage) of 10-course grain-beet crop rotation for the southern part of the Left-Bank Forest-Steppe (cereals – up to 40 %, technical crops – up to 30 %, grain legumes – up to 10 %, forage crops – up to 20 %), where four ways of tillage were investigated: tillage of different depth (22–32 cm); subsurface tillage (22–32 cm); shallow surface tillage (10–12 cm) and minimal surface tillage (5–6 cm) on the background of four fertilization systems – without organic and mineral fertilizers; 15 t/ha humus + $N_{55}P_{55}K_{45}$ (low dose); 15 t/ha humus + $N_{85}P_{75}K_{65}$ (medium dose); 15 t/ha humus + $N_{110}P_{100}K_{85}$ (high dose). The variants were located by split-block design with three repeats. The size of first order plots was 928 sq.m, the second one – 232 sq.m., the area under registration – 1*ntinuous Long-term agronomic experiment No.2.* (The certificate of NAAS No. 040 “The scientific foundations of establishing crop rotations, tillage and fertilization systems in conditions of the Left-Bank Forest-Steppe of Ukraine”) The experiment was conducted in 2001-2014 duntinuous long-term agronomic experiment of the Cherkasy State Experimental station of NSC “Institute of Agriculture of NAAS”. Two types of five-course crop rotations were investigated: A: perennial grass–winter wheat–sugar beet–corn–barley + perennial grass (cereals – up to 60 %, technical crops – up to 20 %; perennial grass – up to 20 %); B: green peas–winter wheat–sugar beet–corn for grain–corn for grain (cereals – up to 60 %, technical crops – up to 20 %; grain legumes – up to 20 %).

Fertilization system: 2001–2015: 6.0 t/ha of by-products; $N_{31}P_{33}K_{41}$ (average dose); $N_{62}P_{66}K_{82}$ (double dose). *The ways of the main tillage:* tillage of different depth (22–25 cm) for all the crops; subsurface tillage (22–25 cm) for all the crops; surface tillage (8–12 cm) for all the crops. There were three repeats in both experiments. The area of the plot for sowing was 250 sq.m., the area under registration – 100 sq.m.

The methods of determining the indices of study objects. To determine the changes in agrochemical, physical, chemical, and agrophysical indices while studying the nutrition regime, humus and agrophysical conditions, mixed samples were selected from one meter deep soil layers in 10 cm distance on different land plots following the schemes of experiments according to DSTU 7030:2009 (GSTU 46.001-96). Soil samples were analyzed according to special methods: granulometric and microaggregate composition – according to Kachynsky (DSTU 4730:2007), structural-aggregate composition – by the sieve method in the modification of Savinov (DSTU 4744:2007) and by the method of Baksheev; the content of total humus – according to Turin’s method in the modification of Simakov (DSTU 4289:2004); humus substances, occurring in the process of peptization of soil colloids – according to Hodlin; active and passive humus (active humus was determined by chromatography) – by the method of Sokolovsky; the content of peculiar humic substances and detritus – according to Springer in the modification of scientists of NSC “Institute for Soil Science and Agrochemistry named after O. N. Sokolovsky”; group and fraction composition of humus – according to Ponomariova and Plotnikova. The calculation method was used to determine: the dispersion factor (DF) – according to Kachynsky; the coefficient of structuredness (Kst) – according to Fageler, the degree of aggregation (Ka) according to Baver and the granulometric index of structuredness –according to Vadiunina; saturation of PC with humus – according to Hodlin, and the indices of erosion resistance (IER) – according to Voronin.

RESULTS AND DISCUSSION

Microaggregates have a feature, relevant in the agrotechnical and meliorative terms, – additional internally aggregated porosity, which determines high quality level of macroaggregates [5, 15, 28.] The aggregate-disperse composition in the 0–30 cm layer of chernozem was determined in conditions of the southern Left-Bank Forest-Steppe in the fourth year since the start of studies in the fields, after the crop rotation of winter wheat-sugar beet-sunflower-annual grass. The experiment was conducted in the variant of systematic tillage and surface tillage at the depth of 10–12 cm without the introduction of mineral and organic fertilizers, and in the variants with the introduction of medium and high doses of mineral fertilizers on the background of humus (Table 1).

There were 23 % of free and friable-linked microaggregates in case of tillage, and 28 % – for surface tillage in the 0-30 cm soil layer in the control (with no mineral and organic fertilizers). The share of silt particles (< 0.001 mm) for surface tillage was decreased 1.8 times. The highest content of free and friable-linked aggregates was found in the 0–20 cm layer at surface tillage, they were 9.6 % more numerous compared to tillage. The content of microaggregates of this group was found to be also higher in the 20–30 cm layer – 22.5 % (surface tillage) and 17.7 % (tillage.) The same numbers of tightly linked microaggregates (0–30 cm) were registered in both variants of soil tillage (43.3–44.6 %); it was true for macroaggregates and macroparticles – 24.5–26.7 %, whereas there were 8 % more mesoaggregates and mesoparticles at systematic tillage compared to surface tillage. The introduction of the average dose of mineral fertilizers on the background of humus ($N_{310}P_{390}K_{250}$ + 60 t/ha of humus) during tillage did not promote any increase in the content of free and friable-linked aggregates in the 0–20 cm layer. Their content decreased by 10 % regarding the control, and increased by 8.3 % in the 20–30 cm soil layer.

In case of surface tillage and introduction of the average dose of mineral fertilizers, the content of friable-linked aggregates decreased by 9.3 % compared to the control with no fertilizers. Both variants had registered increase in the content of free and friable-linked ag-

Table 1. The impact of the tillage and fertilization system on the aggregate-disperse composition of typical medium-humus chernozem in the 4th year since the start of the studies (annual grass)

Layer capacity, cm	Organo-mineral particles, forming		Microaggregates < 0.01 mm				Dispersion factor	Coefficient of aggregation	Index of anti-erosion resistance
			free and friable-linked		tightly linked				
	macroaggregates	mesoaggregates	< 0.01	< 0.01	< 0.01	< 0.01			
tillage (no mineral or organic fertilizers)									
0–20	25.1	15.2	25.2	6.8	40.6	40.1	14.7	91.0	6.0
20–30	23.4	25.9	17.7	2.6	48.7	45.2	5.4	90.0	17.0
($N_{310}P_{390}K_{250}$ + 60 t/ha humus)									
0–20	28.0	26.0	15.0	3.5	54.5	44.1	7.3	94.0	13.0
20–30	29.8	16.0	26.0	2.4	49.0	45.3	5.0	89.0	18.0
($N_{410}P_{410}K_{330}$ + 60 t/ha humus)									
0–20	28.0	26.0	15.0	3.5	54.5	44.1	7.3	94.0	13.0
20–30	29.8	16.0	26.0	2.4	49.0	45.3	5.0	89.0	18.0
Surface tillage, 10–12 cm (no fertilizers)									
0–20	25.7	15.8	31.5	4.7	45.0	42.3	8.9	90.0	10.0
20–30	28.7	12.4	22.5	2.5	60.9	42.7	5.6	93.0	15.0
($N_{310}P_{390}K_{250}$ + 60 t/ha humus)									
0–20	26.3	16.0	20.6	2.0	45.0	42.5	4.4	89.0	19.0
20–30	25.2	23.7	16.2	2.7	49.3	45.6	5.6	81.0	16.9
($N_{410}P_{410}K_{330}$ + 60 t/ha humus)									
0–20	23.3	17.5	24.0	3.0	43.8	42.0	6.6	90.0	13.0
20–30	33.5	13.2	23.5	2.5	51.0	49.5	4.8	89.0	22.0

gregates – in the 20–30 cm layer for tillage, and in the 10–20 cm layer for surface tillage, which was related to the localization of root, after-harvest remains, humus, and mineral fertilizers while conducting the main tillage in autumn. The number of tightly linked aggregates for tillage was somewhat higher compared to surface tillage: 53 and 46 % respectively, but the share of tightly linked microaggregates, sized <0.001 mm, was 10 % higher in the latter case.

The increase in the dose of fertilizers ($N_{410}P_{410}K_{330}$ + +60 t/ha of humus) promoted the increase in the number of free and friable-linked microaggregates up to 24–25 %, and the share of microaggregates, sized < 0.001 mm, was in the range of 9.6–11.8 % for both variants. Here the number of tightly linked aggregates was found to be the same for both variants – 46–47 %. Tightly linked microaggregates were presented with particles sized < 0.001 mm. The number of macroaggregates and macroparticles (> 0.25 mm), mesoaggregates and mesoparticles (0.25–0.001 mm) in the 0–30 cm layer was almost the same, but in case of surface tillage the 20–30 cm soil layer contained 8.3 % more macroaggregates compared to tillage. On the contrary, there were 7.2 % more mesoaggregates for systematic tillage.

In the control with no fertilizers (0-20 cm layer), DF for tillage had a stable tendency towards increasing compared to surface tillage: 15.0 % against 9.0 %. The introduction of the average dose of mineral fertilizers on the background of humus at tillage promoted the increase in DF compared to surface tillage: 5.0–8.5 % against 3.9–5.6 % respectively. Due to the introduction of high doses of fertilizers, DF increased in the 0–10 cm soil layer by 8 % for surface tillage, but remained unchanged in the 10–30 cm soil layer regardless of the way of tillage of typical chernozem.

In the 0–20 cm soil layer in the control (with no mineral and organic fertilizers), IER was 1.67-fold higher for surface tillage, and with the introduction of average doses of mineral fertilizers on the background of humus this index increased 2.1 times for tillage, and 1.9 times – for surface tillage. On the background of high doses of mineral fertilizers, IER for tillage increased both with the introduction of mineral fertilizers and without it, reaching the values of IER = 16–18, whereas in case of surface tillage, IER increased 1.5 times compared to the control without any introduction of fertilizers to the high dose of mineral fertilizers. There were high values of Ka both for tillage and surface tillage. However, medium and high doses of fertilizers for surface tillage conditioned the decrease in the value of Ka in the 0–30 soil layer, which testifies to the dispersing property of mineral fertilizers in the first years of applying surface tillage in the crop rotation.

In the 5^{th} year, similar determination of indices of aggregate-disperse condition of chernozem was conducted for the field of winter wheat. The relevance of the data for the 4^{th} year is in the fact that they were the last ones for the aftereffect of humus, introduced for sugar beet in the first year of studies. The results of determining the aggregate-disperse composition (0–30 cm layer) of typical chernozem demonstrated that in the control with no introduction of mineral and organic fertilizers, the number of free and friable-linked microaggregates decreased in both variants compared to the 4^{th} year of studies, but a higher number of them remained for surface tillage than for tillage. In case of tillage there were 6 % more tightly linked aggregates (< 0.001 mm) compared to surface tillage, and the share of aggregates of the silt fraction in the latter case had a stable increasing tendency. The number of macroaggregates (> 0.25 mm) and mesoaggregates (0.25–0.001 mm) was in inverse correlation: in case of tillage there were 4.5 % fewer aggregates, sized >0.25 mm, than for surface tillage, and 6 % more aggregates of 0.25–0.001 mm. The highest content of organo-mineral particles, participating in the process of macrostructure formation, was found in the 0–10 cm soil layer, and the advantage of surface tillage over tillage was 7 %.

The introduction of average dose of mineral fertilizers affected the formation of free and friable-linked aggregates for tillage and surface tillage: 15.0 % of them were formed in the former case, and 19 % – in the latter. Their highest number was found in the 20–30 cm soil layer for surface tillage – 20.5 % against 15 % for tillage. The number of microaggregates, tightly linked with the mineral part of chernozem (regardless of the way of tillage), was found to be almost the same (43.4 and 46.5 %), but the number of silty particles in the latter case was 8 % lower, which testifies to the decrease in the dispersion of the 0–30 cm chernozem layer at systematic surface tillage.

The introduction of high doses of mineral fertilizers affected the number of tightly linked aggregates (0–30 cm) which was almost the same – 44.8–45.7 % regardless of the way of tillage, but the number of silty particles for surface tillage was higher compared to tillage. In case of tillage there was a registered increase in the content of aggregates, sized > 0.25 mm: their number reached 5.9 and 7.7 % in the soil layers of 0–20 and 20–30 cm, which testified to the soil dispersion at the introduction of high doses of mineral fertilizers in case of systematic implementation of surface tillage for 10–12 cm. If in case of introducing average doses of mineral fertilizers, DF had the value of 6–7 %, in case of high doses it was 8–9 %. IER in the variants of tillage and surface tillage had high values, but in case of tillage they were higher in absolute values. When high doses of mineral fertilizers were introduced for surface tillage, IER values decreased down to the middle level (8–10), which testified to the harmfulness of the introduction of high doses of mineral fertilizers.

In the 7th year since the start of the studies, there was an investigation of the capability of typical chernozem to have microaggregation during systematic tillage and surface tillage for 10–12 cm in the variants with the introduction of the middle and high doses of fertilizers on the background of 60 t/ha of humus, introduced for the field of sugar beets.

A relevant index of humus horizon resistance in chernozem was the stability of aggregate-disperse composition during the vegetative period, thus the determination was performed in dynamics – three times for the vegetative period. It was established that the number of free and friable-linked aggregates in the control (with no mineral and organic fertilizers) increased from spring to summer. A similar regularity was remarkable for variants with introduced mineral fertilizers in different doses on the background of humus. In case of systematic tillage in April, there were 8–9 % more of the mentioned aggregates compared to surface tillage, but till the middle of summer (with surface tillage) the number of free and friable-linked aggregates increased by 5–7 %. There was remarkable increase in the number of free and friable-linked microaggregates with the introduction of increasing doses of fertilizers for surface tillage: in July, their number increased up to 19–22 and 21–24 % respectively, till the introduction of medium and high norms of fertilizers. At the same time, there were 16–17 and 19 % of aggregates for tillage, respectively.

In spring, in case of surface tillage the number of tightly linked aggregates (< 0.01 mm) in the control (with no mineral fertilizers) was higher than that for tillage. The introduction of increasing doses of mineral fertilizers somewhat decreased the number of these aggregates, but in case of tillage the decrease in their content was more remarkable. In case of introducing high doses of mineral fertilizers, the number of tightly linked aggregates in both variants of tillage in the 0–30 cm soil layer was the same, which testified to dispersing nature of high doses of fertilizers in long-term implementation of both tillage and surface tillage. However, there were 10 % more tightly linked aggregates in the subsurface layer (30–40 cm) in case of surface tillage in spring.

The determination of the ratio of microaggregates sized 0.05–1 and 0.01–0.05 mm during the vegetation period allowed a conclusion that in the control (with no mineral and organic fertilizers) in case of surface tillage there were much more aggregates sized 0.05–1 mm (by 5–8 %) compared to tillage, and the content of microaggregates was more stable time-wise, compared to tillage. The introduction of average doses of mineral fertilizers had different effect on the content of meso- and microaggregates during tillage and surface tillage. In the latter case, during the vegetative period, there were 1.5–2.2 times more aggregates, sized 0.5–1 mm in the 10–30 cm soil layer, and in case of tillage there was a considerable increase (by 10 %) in the number of aggregates sized 0.01–0.05 mm. The introduction of high doses of mineral fertilizers decreased the number of aggregates sized 0.05–1 mm at surface tillage, but there were more of them than during tillage both in spring and in summer. The tillage with the introduction of high doses of mineral fertilizers promoted the increase in the number of aggregates sized 0.01–0.05 mm, but their number decreased remarkably till summer. On the contrary, in case of surface tillage, fewer aggregates of this size were formed in spring, and till summer their content was stabilized at the level of content for tillage.

In case of surface tillage, the DF value was at the level of 3–4 % during the vegetative period. The highest value of DF in the 0–10 cm soil layer was registered in the middle of summer for systematic tillage – 6–7 %. With the introduction of average doses of mineral fertilizers during surface tillage, DF was at the level of 3–5 % only in the 0–10 cm layer, and in May it was up to 6 %. With systematic tillage in the crop rotation at the beginning of the vegetative period, DF in the 0–30 cm soil layer was 4–6 %, and by the end of the vegetative period it increased up to 7–9 %. The anti-erosion resistance of the humus horizon for surface tillage was higher than for tillage both in the variant with no fertilizers and in case of introducing high and medium doses of mineral fertilizers. The use of high doses of mineral fertilizers during tillage decreases the IER values to the medium level (< 10) whereas during surface tillage IER had the values > 10 regardless of the way of tillage.

In the 9th year of studies, there was determination of the level of aggregate-disperse composition of typical chernozem under corn for grain with the introduction of the average dose of mineral fertilizers in four variants of cultivation. At first $N_{710}P_{670}K_{565}$ and 150 t/ha of humus were applied, with subsequent $N_{110}P_{75}K_{75}$ and 30 t/ha of humus to sow corn. The calculation of DF demonstrated that in case of tillage (0–30 cm) DF values were 8–11 %, and the highest value was registered in the 5–10 cm layer – 15 %. In case of deep surface tillage, DF was at a high level only in the 0–5 cm layer – 7.5 %, and decreased deeper down to 2.9 % (20–30 cm). In case of surface tillage for 5–12 cm, DF (0–5 cm) had the values of 11 %, and in the 5–10 cm soil layer – 9.1 %. DF values in the deeper layers of humus horizon (10–20 and 20–30 cm) decreased down to 4.9–5.6 %. The systematic surface tillage for 5–6 cm increased DF up to 9.7–10 % in the layers of 0–5 and 5–10 cm, and decreased it in the 10–30 cm layer down to 2.7–2.8 %. In the subarable layer (30–40 cm) with tillage and surface tillage for 5–12 cm, DF was at the level of 5.0–5.9 % and at deep surface tillage it reached 8 %.

The calculation of IER demonstrated that tillage for nine years with the introduction of average doses of mineral fertilizers on the background of humus did not promote the increase in the anti-erosion resistance of arable layer. IER values in the 0–5 cm layer reached 10, while it decreased down to 5–7.5 in the 5–30 cm layer. In case of surface tillage for 22–32 cm in the 0–30 cm soil layer, IER values increased up to 10, and equaled 5–6 in the 30–40 cm soil layer. Surface tillage for 5–12 cm on the background of organo-mineral system of fertilization in the surface layers (0–5, 10–15 cm) somewhat decreased IER values down to the level of 7–8 %, and in the soil layers of 10–20 and 20–30 cm the anti-erosion resistance increased up to 12.6–15.2 and 26.6–26.8 according to tillage.

The last crop in the rotation was corn for sillage. During 10 years, $N_{820}P_{730}K_{625}$ of the active substance of mineral fertilizers was introduced on the background of 150 t/ha of humus, which on average was $N_{80}P_{75}K_{65}$

Table 2. The impact of the tillage system on typical medium-humus chernozem on aggregate-disperse composition by the end of crop rotation ($N_{850}P_{750}K_{650}$ 150 t/ha of humus)

Layer capacity, cm	Organo-mineral particles, forming		Microaggregates (< 0.01 mm)				Saturation of physical clay with humus, %
			free and friable-linked		tightly linked		
	macroaggregates	mesoaggregates	< 0.01	< 0.01	< 0.01	< 0.01	
Tillage for over 75 years							
0-20	3.2	43.7	18.0	1.9	47.2	37.1	0.079
30-40	6.3	41.7	17.0	3.2	45.9	33.8	0.078
Tillage for 22–32 cm (experiment)							
0-20	3.7	38.9	23.0	3.7	42.9	37.1	0.098
30-40	3.8	38.9	27.0	3.8	37.9	33.8	0.100
Surface tillage for 22–32 cm (experiment)							
0-20	4.3	37.9	26.5	3.1	41.5	36.1	0.102
30-40	4.8	38.9	27.0	3.8	37.9	33.2	0.108
Surface tillage for 10–12 cm (experiment)							
0-20	5.5	40.6	28.0	2.8	37.7	36.2	0.100
30-40	4.5	39.3	31.0	4.0	35.0	33.0	0.099
Surface tillage for 5–6 cm (experiment)							
0-20	4.3	39.6	21.4	2.8	45.4	36.6	0.104
30-40	7.7	36.2	22.0	4.0	42.1	34.5	0.108
Fallow for 10 years							
0-20	7.0	38.0	27.0	2.5	39.5	36.5	0.103
30-40	9.0	31.0	26.0	3.6	40.0	33.4	0.108

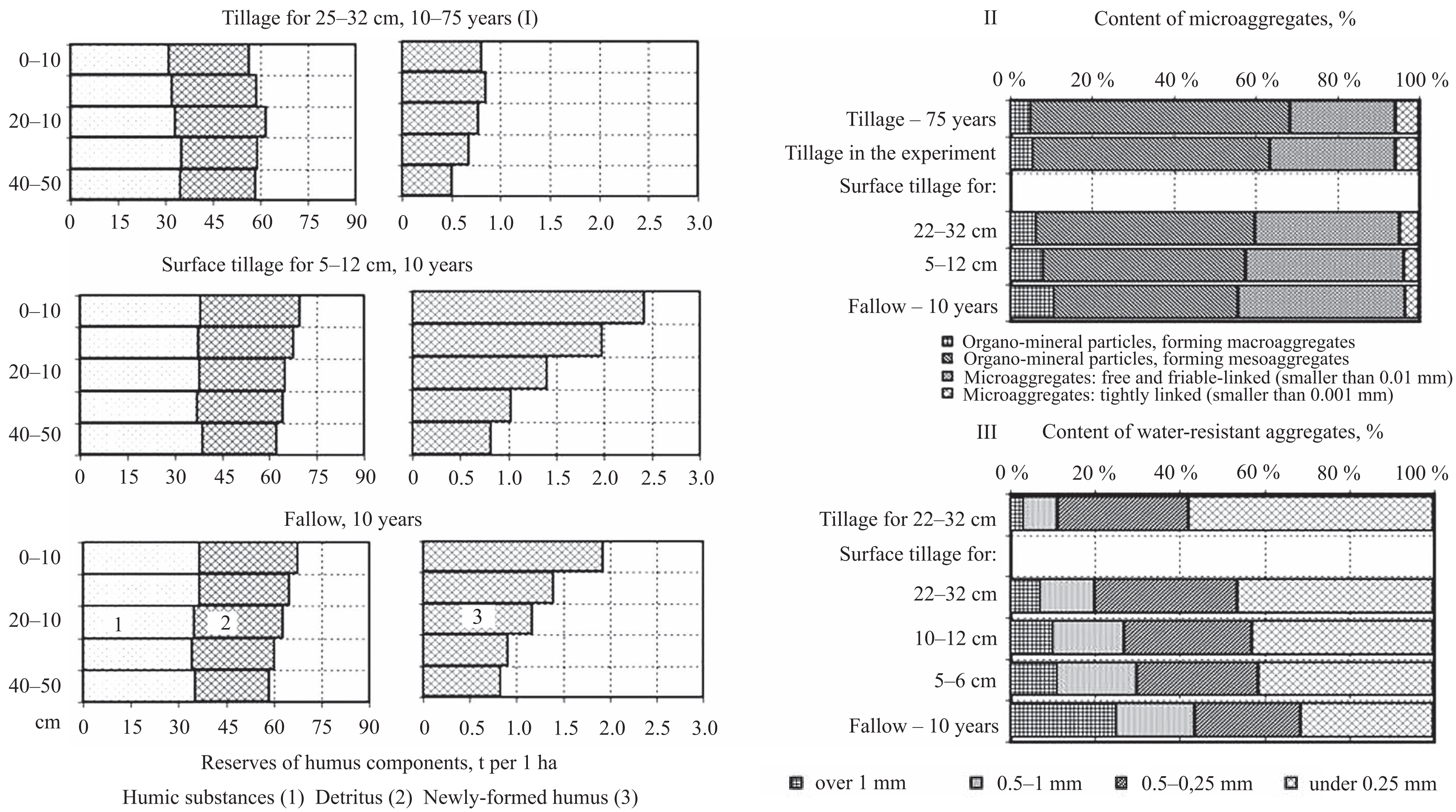


Fig. 1. The impact of the system of tillage and cultivation of typical medium humus light loamy chernozem on humus composition (I), microaggregate composition (II) and water resistance of structural units of 2–5 mm (III) on the 10th year of studies, $N_{85}P_{75}K_{65}$+15 t of humus per 1 ha of crop rotation

and 15 t/ha of humus. Table 2 and Fig. 1 present the aggregate-disperse composition of typical chernozem at the end of crop rotation. The comparison considered the results of determining the aggregate-disperse composition for tillage during over 75 years and 10 year-long fallow. During long-term tillage (over 75 years) the number of free and friable-linked aggregates decreased down to 17–20 % (0–20 cm) and 17 % (30–40 cm). The application of tillage on the background of organo-mineral system of fertilization promoted the increase in the content of free and friable-linked microaggregates in the 0–20 cm layer up to 22–23 % and in the 30–40 cm layer – up to 27 %. Systematic surface tillage for 22–32 % increased the content of free and friable-linked aggregates up to 26–27 % in the 30–40 cm soil layer, and in case of shallow surface tillage – up to 28–31 %.

The minimization of the main soil tillage to 5–6 cm did not promote the increase in the content of this group of aggregates. The share of aggregates < 0.001 mm in the total number of free and friable-linked microaggregates in the 0–20 cm soil layer was in the range of 10–14 %, and in the 30–40 cm soil layer – 18–19 %. In other variants in the experiment the share of free and friable-linked microaggregates changed in the range of 13–14 %, and the number of tightly linked microaggregates sized < 0.01 mm (0–20 cm) decreased from tillage (over 75 years) to shallow surface tillage for 10–12 cm.

The minimal tillage for 5–6 cm somewhat disrupted the established regularity of forming the ratio of microaggregate groups, which may be explained by the specificity of water and temperature regimes and the character of transformation of organic substance. The content of microaggregates increased from tillage to minimal soil protective tillage. There was a corresponding decrease in the content of mesoaggregates and microaggregates. The comparison of the microstructure to fallow variants (75 years) and fallow (10 years) yielded a conclusion that surface tillage (from the one for different depths to 22–32 cm up to 5–12 cm) promoted the modelling of natural microaggregation process. Minimal tillage exceeded tillage by the tempo of the formation of macroaggregates sized 0.05–1 mm. The introduction of high doses of mineral fertilizers on the background of humus had negative effect on chernozem microstructure both during tillage and surface tillage: the content of mesoaggregates increased up to 50–60 %, and the number of macroaggregates (0.05–1 mm) decreased.

Hodlin [10] considered the number of free and friable-linked aggregates in soil to be of great relevance and related their formation to the synthesis of newly-formed humic acids, which were easier to get subject to mineralization processes. In his studies the author demonstrated that tightly linked aggregates had more humic substances, nitrogen and sesquioxides of iron and aluminum, and the ignition loss was higher than that for free and friable-linked aggregates. At the same time, there was no difference in the number of consumed Ca and Mg. Friable-linked microaggregates had higher biological activity compared to soil. This phenomenon may be explained by the fact that organic matter of tightly-linked aggregates was closer linked to the mineral part of soil due to the availability of a high number of hydrooxides of iron and aluminum, and thus was less mobile. In addition, humic substances of this group of microaggregates were more subject to aging, which decreased their biological activity.

The correlation of our studies to Hodlin's conclusions [11, 12] promotes a statement that systematic tillage for over 75 years led to the dehumification of the arable layer, and thus to the decrease in the content of free and friable-linked microaggregates. Tillage on the background of the organo-mineral system of fertilization promoted the increase in the content of free and friable-linked microaggregates, but this process was characterized by temporal instability. The number of free and friable-linked microaggregates may be increased or decreased depending on the way of tillage, number of introduced fertilizers and a crop, sown in the crop rotation.

Systematic implementation of soil-protective technologies in the crop rotation (18 years) led to the increase in the number of free and friable-linked microaggregates, which was evident in the 3-4th year since the introduction of these technologies. In our opinion, this phenomenon is related to the fact that more humic substances were formed in the first years of introducing surface tillage. A higher amount of newly-formed humus is related to the increase in the biogenicity of microaggregate composition and may be the feature of cultural soil formation.

Meanwhile Hodlin [9] paid attention to the fact that there was an agronomically relevant criterion for chernozems: if a number of microaggregates, actively participating in the formation of stable meso- and macroaggregates, exceeded 40 %, there were all the conditions to restore the forfeited grain-like finely crumbly structure of the arable layer.

The studies and calculations demonstrated that regardless of the tillage system typical medium-humus heavy loamy chernozem had high content of such aggregates (> 40 %) which testified to a high ability of restoring the structural condition. The application of surface tillage led to the increase in the number of organo-mineral particles, forming macroaggregates. The process of the formation of organo-mineral elements was directly related to the character of embedding and localization of organic fertilizers and afterharvest residue: in case of tillage – in the lower part of the arable layer, and in case of surface tillage – in the upper one. In the authors' opinion, noteworthy are Hodlin's conclusions [11] about humus localization in the microaggregates sized > 0.01 mm. The coefficient of saturating physical clay with humus (K_{PC}) during tillage for over 75 years in the 0–40 cm soil layer equaled 0.076–0.084, or 7.6–8.4 %. Tillage on the background of organo-mineral fertilization system increased the saturation of PC with humus up to 8.9 % in the 0–5 cm soil layer and up to 10.1–10.5 % in the soil layers of 5–20 and 30–40 cm. Similar values of saturating PC with humus were found while implementing soil protective systems of tillage of different depth and intensity.

The determination of the impact of different ways of tillage and fertilization of typical light loamy heavy clay-silt chernozem on microaggregation is presented in Table 3. It was established that while implementing surface tillage for 5–12 cm in the control with no fertilizers the number of microaggregates sized > 0.25 mm increased by 3.12 % or 1.5-fold. The introduction of organic fertilizers in the form of humus, straw, and mineral fertilizers during surface tillage enhanced the process of chernozem microaggregation: 7.6–9.4 % more

Table 3. The impact of different systems of tillage and fertilization on the microaggregate composition in the 0–20 cm layer of typical low humus light loamy chernozem of the central Left-Bank part of the Forest-Steppe of Ukraine

Introduction of fertilizers	Size of fractions (mm), content, %					Factor		Index of anti-erosion resistance
	> 0.25	0.25–0.05 (a)* / 0.05–0.01 (c)	*c to a	> 0.01	≤ 0.01 / < 0.001	of dispersion	potential aggregation	
Tillage for 22–32 cm								
Control (no fertilizers)	5.78	23.16 / 60.50	2.60 to 1	89.44	10.56 / 1.91	10.0	0.20	2.00
$N_{65}P_{60}K_{50}$ + 12 t/ha of humus	9.60	18.21 / 61.0	3.3 to 1	88.81	11.19 / 0.57	2.76	0.21	7.61
$N_{65}P_{60}K_{50}$ + 1.5 t/ha of straw	5.49	22.65 / 64.36	2.8 to 1	92.50	7.50 / 1.25	7.70	0.18	2.35
Surface tillage for 22–32 cm								
Control (no fertilizers)	5.61	20.75 / 62.40	3.0 to 1	88.76	11.23 / 1.37	6.28	0.27	4.10
$N_{65}P_{60}K_{50}$ + 12 t/ha of humus	8.48	19.7 / 63.0	3.2 to 1	91.18	8.82 / 0.64	2.02	0.21	10.4
$N_{65}P_{60}K_{50}$ + 1.5 t/ha of straw	6.12	28.1 / 58.05	2.1 to 1	92.27	7.74 / 1.38	7.77	0.22	2.83
Surface tillage for 10–12 cm								
Control (no fertilizers)	8.90	29.65 / 52.95	1.8 to 1	91.50	8.50 / 0.81	3.96	0.22	5.56
$N_{65}P_{60}K_{50}$ + 12 t/ha of humus	17.19	26.40 / 48.70	1.8 to 1	91.77	8.23 / 0.52	2.64	0.23	8.71
$N_{65}P_{60}K_{50}$ + 1.5 t/ha of straw	14.90	23.30 / 52.45	2.3 to 1	90.65	9.35 / 1.35	6.34	0.22	3.47

*Note: a – number of humus-containing mesoaggregates (numerator); c – number of non-humus-containing mesoparticles (denominator) [13].

microaggregates sized > 0.25 mm were formed, which was 1.7–2.7 times more compared to tillage. With the minimization of tillage, the number of microaggregates sized 0.25–0.05 and 0.05–0.01 mm increased both regarding the control with no fertilizers and with the introduction of organo-mineral fertilization system, and the ratio between the content of microaggregates of the mentioned size decreased towards larger fractions, sized 0.25–0.05 mm. There were 1.24–1.36 times fewer particles sized < 0.01 mm for minimal tillage compared to tillage.

DF in the variants with no introduction of fertilizers decreased 1.24 times from tillage to surface tillage, and during the introduction of humus on the background of mineral fertilizers DF had not a high value (2.02–2.76) during tillage and surface tillage, but this index decreased with the minimization of chernozem tillage.

The index of potential aggregation (Pa) regardless of the system of tillage and fertilization was the same but the IER value in the 0–20 cm soil layer during minimal tillage increased regarding tillage 2.78 times with no fertilizers, 1.15 times – with the introduction of humus with mineral fertilizers, and 1.5 times – with the introduction of straw with mineral fertilizers. Here water resistance of microaggregates with large fractions increased. A higher content of free and friable-linked aggregates increased the biogenicity of the cultivated layer and promoted the improvement of the agrophysical condition and nutrition regime of chernozem.

The intensive cultivation (tillage) of chernozem promoted the increase in the content of active forms of humus due to biological transformation of some passive humus into its active form: humus got renewed due to the mineralization of humic substances, which was related to the decrease in its content and reserves. In conditions of surface tillage the 2.04-fold increase in the content of active form of humus (0–50 cm soil layer) occurred due to the synthesis of free organic substance: a share of newly formed humus in the 0–20 cm chernozem layer from the total amount of active form of colloid humus was 53–55 %, and during tillage – not more than 43–45 %, with the 2.29–2.3-fold increase of the reserves.

A relevant agent of increasing microbiological activity and microaggregation of chernozem is detritus, which, on the one hand, is the adsorbent of humic and newly formed substances, and on the other, plays the role of “carcass” while forming agronomically valuable water-resistant aggregates. During tillage for over 75 years and tillage in the experiment conditions the content of detritus was 28–31 % from the total reserves of humus, and its highest amount was formed in places of localization of afterharvest, root remains and humus, *i.e.* in the 15–35 cm layer. In conditions of deep surface tillage the reserves of detritus in the 0–50 cm layer were 1.16–1.4 times higher regarding the variant of long-term and deep tillage. The highest accumulation of detritus occurred in the 0–20 cm soil layer, where the total reserves of detritus were 31–32 % from the reserves of total humus.

The minimization of chernozem tillage to the depth of 5–12 cm promoted the increase (1.10–1.25 times) of detritus content compared to tillage and deep surface tillage. The share of detritus in the total humus reserves during shallow and minimal surface tillage was 31–32 % and the re-distribution of detritus in the 0–50 cm layer was in the surface layer of soil. The 0–20 cm soil layer contained 60–65 % of detritus from all the reserves in the 0–50 cm soil layer. The general regularity of accumulation and redistribution of detritus while maintaining fallow was similar to surface tillage for 5–12 cm with the only difference – the whole 0–50 cm chernozem layer had high reserves of detritus (Fig. 1).

The root system of agricultural crops is the main source of physiologically active substances, which, during the whole vegetative period, plays the main role in soil-forming properties of crops in the crop rotation and, using their root exudates, is capable of forming soil microstructure in agrophysical meaning. Thus, root exudates are of extreme relevance in enhancing morphogenetic features of chernozem, the number of which is directly linked to the action of abiotic factors in soil medium. The microstructure is formed in the active rhizosphere of root systems of agricultural crops.

The layer-wise reserves and redistribution of roots in the humus horizon (0–40 cm) of typical chernozem was defined for the crop rotation (Fig. 2). The effect of the system of tillage and introduced fertilizers is reflected on the redistribution of roots. During tillage the root system grows deeper inside the cultivated layer, and in case of surface tillage it is formed by the turf type: 80.5–87.4 % of the roots from the whole mass are concentrated in the 0–10 cm chernozem layer during minimal tillage. The differentiation of root redistribution in the humus horizon of chernozem is enhanced with the minimization of the main way of chernozem tillage, and the total content of roots in

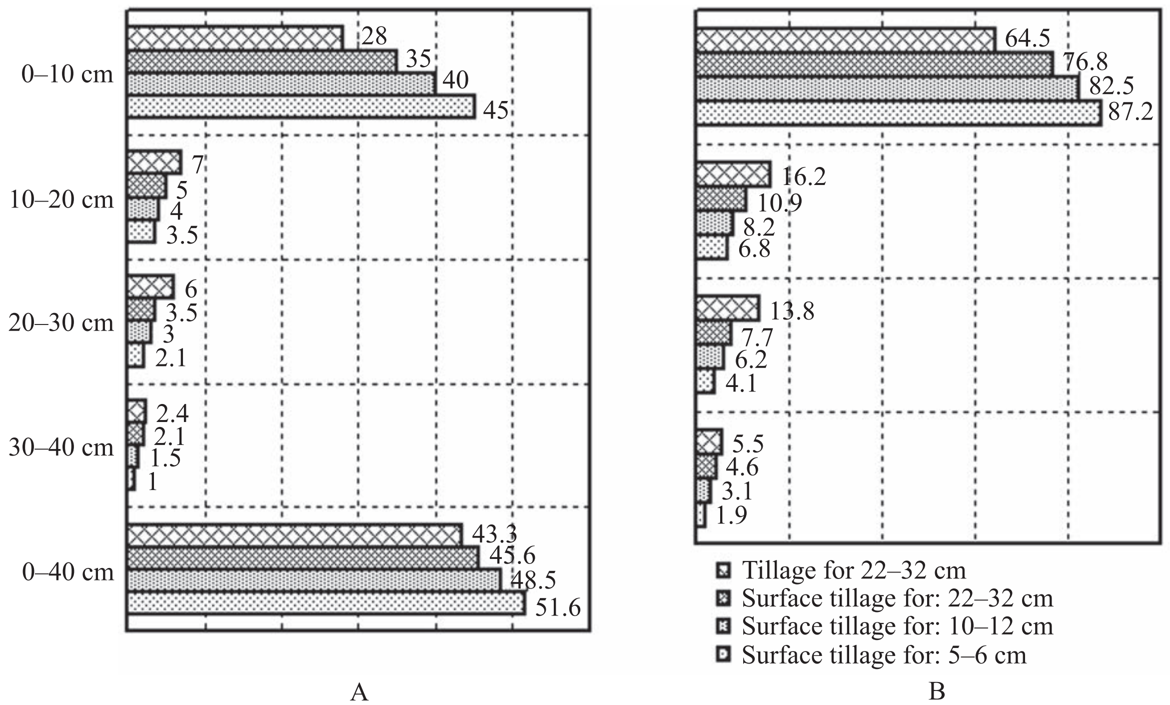


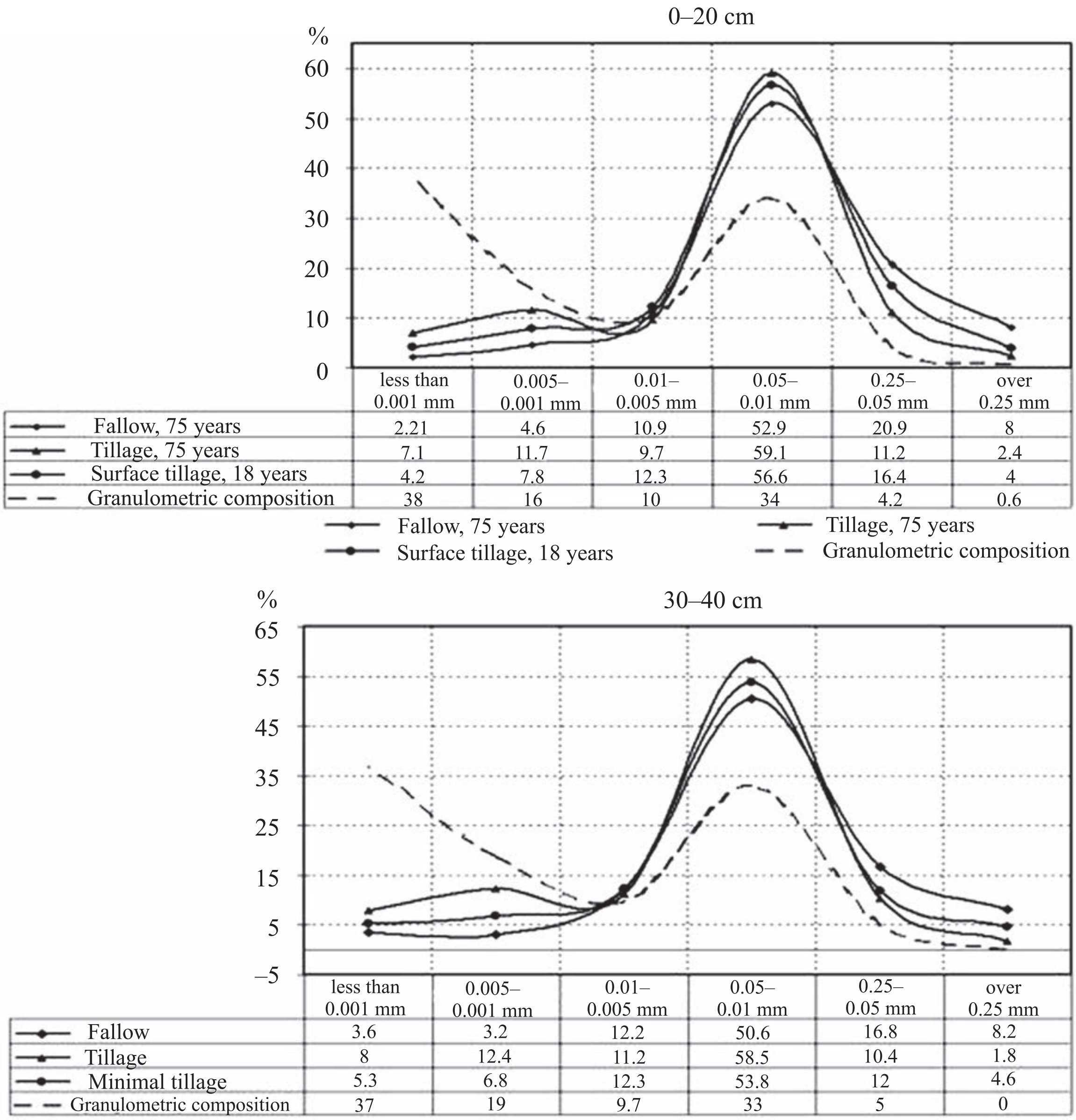
Fig. 2. The impact of the tillage system on A – reserves (t/ha) and B – content (%) of roots in the humus horizon of chernozem for the crop rotation

the humus horizon increases with the minimization of tillage (Fig. 2).

Due to the simulation of the turf process of soil formation, the aggregation at the level of microaggregates involved more particles sized < 0.01 mm, which decreased the dispersion factor and increased antierosion indices of the cultivated layer. The minimization of the main tillage during surface tillage was more efficient in promoting the activation of microaggregation processes compared to tillage and deep surface tillage, which changed towards wild land and fallow variants of maintaining chernozem, which testified to the restoration of natural soil formation in the agrocenosis at the microaggregate level.

Long-term application of surface tillage stimulated the re-grouping of microaggregates towards the increase in their sizes, similar to long-term fallow. While in case of fallow the microaggregation covered the 0–20 cm soil layer, with surface tillage there was an increase in the microaggregation process of humus horizon of chernozem. In general, there was the simulation of a natural microaggregation process while implementing surface tillage and ruining the microstructure with systematic tillage (Fig. 1, 2).

Enhancing the microaggregation by turf type in the agrocenoses requires enriching the upper third of the humus horizon of chernozem with detritus, ensuring high biological activity of the 0–15 cm chernozem layer and forming an organogenic layer (contact zone) in the upper third of the humus horizon of chernozem with high microbiological activity, which increases by a third with surface tillage (0–30 cm), with the 1–17-1.25-fold increase in the microbial cenosis. The number of earthwarms in the 0–20 cm layer of humus horizon during surface tillage increased 1.62–1.86 times compared to tillage, which increased the looseness of humus horizon by 15–25 %. The enrichment of chernozem with detritus from the surface was ensured by springtails and mites, the number of which increased by 126–144 %. The enhanced growth of root systems of agricultural crops by turf type, the restoration of soil variety during surface tillage may be qualified as a feature of changes in soil formation towards its increase (imitation simulation by a number of features) of the turf process, based on annual intake of root and ground biomass of agricultural crops (7–10 t/ha) with its packing into the upper third of humus horizon using surface tillage, which ensured the formation of transformation-migration type of humus profile with descending migration of humification products of typical chernozem in agrocenoses. Better conditions of humus accumulation in anaerobic conditions of decomposition of organic fertilizers during surface tillage were demonstrated by Vostrov [37] and confirmed with our studies [25, 28].



0–20 cm	less than 0.001 mm	0.005–0.001 mm	0.01–0.005 mm	0.05–0.01 mm	0.25–0.05 mm	over 0.25 mm
Fallow, 75 years	2.21	4.6	10.9	52.9	20.9	8
Tillage, 75 years	7.1	11.7	9.7	59.1	11.2	2.4
Surface tillage, 18 years	4.2	7.8	12.3	56.6	16.4	4
Granulometric composition	38	16	10	34	4.2	0.6

30–40 cm	less than 0.001 mm	0.005–0.001 mm	0.01–0.005 mm	0.05–0.01 mm	0.25–0.05 mm	over 0.25 mm
Fallow	3.6	3.2	12.2	50.6	16.8	8.2
Tillage	8	12.4	11.2	58.5	10.4	1.8
Minimal tillage	5.3	6.8	12.3	53.8	12	4.6
Granulometric composition	37	19	9.7	33	5	0

Fig. 3. Long-term effect of the ways of tillage on aggregate-disperse condition of typical chernozem

Medvedev [15] demonstrated that the aggregation potential depended on the granulometric composition and on the size of particles (or microaggregates), corresponding to the crossing point for the curves of granulometric and aggregate conditions. The increase in the content of clay and silt particles led to the increase in the number of microaggregates and the aggregation potential.

Table 4 presents the values of paired correlation coefficients between the groups of microaggregates, water-resistant aggregates and humus content, capable of peptization depending on the tillage system. The calculation demonstrated that the correlation coefficient between the crossing point for the curves of granulometric and microaggregate analysis, relative to the content of microaggregates of < 0.01 mm, was R= –0.14 for tillage, which increased to the average level of R= = +0.50 for surface tillage.

Maintaining chernozem in the fallow state for 10 years decreased the correlation coefficient down to the low level of R= –0.14. The consideration of the established connection and calculations for aggregate-disperse indices allowed for the conclusion that tillage of typical chernozem for a long time preserved potential possibilities for the formation of macrostructure.

Fig. 3 presents the aggregate-disperse condition of typical medium humus chernozem during long-term tillage, long-term surface tillage, and long-term fallow.

It was determined that long-term surface tillage promoted the increase in the content of microaggregates, sized 0.05–0.25 mm by 5.2 %, compared to long-term tillage, and those larger than 0.25 % – by 1.6 %. The number of microaggregates, smaller than 0.001 and 0.001–0.005 mm, was 1.7 and 1.5 times lower. Similar processes took place in the 30–40 cm soil layer: there were 1.6 and 2.7 % more microaggregates sized 0.05–0.25 mm and smaller than 0.25 mm for surface tillage, and there were 2.7 and 5.6 % fewer microaggregates, smaller than 0.001 and 0.001–0.005 mm. There were 4.7 % more fractions of microaggregates than during long-term tillage.

Our conclusions coincide with those of Medvedev [23], based on the fact that the crossing point for the curves of granulometric and microaggregate composition is about 0.01 mm (the deviations are in the range of 0.037–0.007) regardless of the nature of agricultural application of soils. The availability of a large number of microaggregates, sized > 0.01 mm, in the tilled chernozem creates the prerequisites for the formation of the agronomically valuable structure.

Further calculations revealed a tight relationship at the level of close correlation between the content of hu-

Table 4. The values of paired correlation coefficients between the groups of microaggregates, aggregates and content of humus substances, capable of peptization depending on the tillage system

Paired correlation coefficients							Index	
X_1	X_2	X_3	X_4	X_5	X_6	X_7		
Tillage for 22–32 cm								
1	+0.75	–0.45	+0.13	+0.37	+0.65	–0.18	*Size of particles, μm	X_1
–	1	–0.17	+0.27	+0.36	+0.37	–0.07	** < 0.01 (m/s)	X_2
–	–	1	–0.40	–0.41	+0.17	–0.73	** < 0.01 (g/s)	X_3
–	–	–	1	–0.89	+0.22	+0.74	0.05–0.01	X_4
–	–	–	–	1	+0.48	+0.54	0.01–0.25	X_5
–	–	–	–	–	1	–0.70	Substances, capable of peptization of humic substances, t/ha	X_6
–	–	–	–	–	–	1	Water-resistant aggregates 3–0.5 mm	X_7
Surface tillage for 10–12 cm								
1	+0.50	–0.14	+0.46	+0.65	+0.50	+0.03	*Size of particles	X_1
–	1	–0.20	+0.25	+0.16	+0.60	+0.02	** < 0.01 (m/a)	X_2
–	–	1	–0.71	–0.30	–0.12	–0.73	** < 0.01 (g/s)	X_3
–	–	–	1	–0.76	+0.50	+0.65	0.05–0.01	X_4
–	–	–	–	1	+0.72	+0.21	0.01–0.25	X_5
–	–	–	–	–	1	–0.15	Substances, capable of peptization of humic substances, t/ha	X_6
–	–	–	–	–	–	1	Water-resistant aggregates 3–0.5 mm	X_7
Wild land and fallow								
1	–0.14	–0.40	+0.35	+0.28	–0.14	+0.20	*Size of particles	X_1
–	1	–0.25	–0.03	+0.04	–0.18	–0.13	** < 0.01 (m/a)	X_2
–	–	1	–0.30	–0.42	–0.57	–0.65	** < 0.01 (g/s)	X_3
–	–	–	1	–0.78	–0.65	–0.40	0.05–0.01	X_4
–	–	–	–	1	+0.66	+0.01	0.01–0.25	X_5
–	–	–	–	–	1	–0.07	Substances, capable of peptization of humic substances, t/ha	X_6
–	–	–	–	–		1	Water-resistant aggregates 3–0.5 mm	X_7

*The content of particles, corresponding to the crossing point for the curves of granulometric (g/s) and microaggregate composition (m/s); **content of microaggregates (X_3) and granulometric particles (X_2) to the crossing point of distribution curves.

mus substances, capable of peptization, and the content of aggregates, sized 0.01–0.25 mm (X_5). Systematic implementation of tillage in the crop rotation weakens the level of relationship (R = +0.48) down to the medium and low ones, and systematic implementation of surface tillage for 10–12 cm and maintaining fallow increases the relationship to the level of close correlation: R = +0.66–0.72.

The level of reverse correlation demonstrated the content of microaggregates sized 0.01–0.25 mm (X_5) and 0.05–0.01 mm (X_4) in all the variants: R = –0.76–0.89. The calculations demonstrated direct close relationship between the content of microaggregates sized 0.05–0.01 mm (X_4) and the number of water-resistant aggregates sized > 3 mm (X_7), which testifies to potential possibilities of forming a water-resistant structure while implementing different systems of tillage.

The application of surface tillage promoted the increase in the ability of chernozem to form water-resistant aggregates and enhanced anti-erosion resistance of the 0–30 cm soil layer. The increase in the number of free and friable-linked microaggregates should be considered a positive phenomenon in terms of improving the nutrition regime of plants and enhancing chernozem biogenicity at the microaggregate level. There are all the grounds for the assumption that in cases of tillage and shallow surface tillage the aftereffect of the introduced humus with the introduction of average doses of mineral fertilizers is the same, while with the introduction of high doses of fertilizers there is dispersion of the 0–30 cm soil layer, though the number of free and friable-linked microaggregates remains high during soil protective tillage. The average dose of mineral fertilizers during surface tillage for 5–12 cm should be considered the optimal one. Systematic application of soil protective technologies in the crop rotation with the introduction of average doses of mineral fertilizers optimizes the ratio of micro- and macroaggregation forms of humus.

The presented data demonstrated that typical medium and low humus heavy and light loamy chernozem of granulometric composition were highly capable of structuring, and the degree of saturating PC with humus testified that the humus content in chernozem was optimal at the level of 4.0–5.0 %. In case of such content, humus is neither accumulated in the form of free humates, nor stored like “fat” in animal organisms, and there is no blocking of nutrients with free humates. With optimal saturation of PC of chernozem with humus, the latter acts as “connective tissue” due to its components, which promotes the improvement of structural-aggregate condition of chernozem.

CONCLUSIONS

Systematic implementation of soil protective technologies in agrocenoses ensures the optimization of the ratio in micro- and macroaggregation forms of humus, which enhances microstructuring of chernozem in humus horizon; while the increase in the number of free and friable-linked microaggregates with their own well-developed porosity increases chernozem biogenicity and the conditions of restoring the microstructure. Due to enhancing quality indices of humus, more clay particles are involved into microaggregation, which decreases the dispersion factor and increases the anti-erosion indices of humus horizon of chernozem in agrocenoses.

In case of surface tillage, the number of microaggregates, participating in the formation of stable meso- and macroaggregates in chernozem, exceeds 40 % which creates conditions for the restoration of forfeited finely-crumbly-grainy structure of chernozem. The number of free and friable-linked microaggregates of chernozem ensures a high level of biological activity, the intensity of synthesis of newly formed humus substances and detritus, and the degree of saturation with humus determines the direction of soil formation. During long-term tillage (for over 75 years) the number of free and friable-linked aggregates in the 0–40-cm chernozem layer decreases down to 17–20 %, and at the background of organic-mineral system of fertilization (15 t/ha of humus + $N_{80}P_{75}K_{60}$) there is an increase in the content of the mentioned groups of microaggregates up to 20–25 %.

The systematic implementation of soil protective technologies promotes the increase in the content of free and friable-linked microaggregates up to 30–32 %. During tillage the coefficient of physical clay saturation with humus decreases 1.3–1.4-fold compared to fallow and is at the level of fallow values. The value of physical clay saturation during the soil protective tillage is optimal, as humus is neither accumulated in the form of free humates, nor stored like “fat” in animal organisms, and there is no blocking of nutrients with free humates. Humus acts as a connective tissue, promoting the improved water-resistance of chernozem structure on the micro- and macroaggregate levels.

The ability of chernozems to have microaggregation is determined by the dispersion factor, which is 12–14 % during tillage without introducing any fertilizers, and 10 % – with the introduction of fertilizers, which testifies to a weak degree of microaggregation. With minimal tillage on the background of the organo-mineral system of fertilization, DF = 6–7 %, and by the end of rotation it decreases down to 3–5%.

Enhanced microaggregation in soil protective technologies is explained by the fact that detritus and newly formed humic substances enhance their role in the formation of organo-mineral complexes in case of optimization of hydrothermal conditions in the seasonal cycle and the decreased tempo of humus mineralization. The correlation coefficient between the number of microaggregates, sized 0.01–0.25 mm and the content of peptized humic substances during tillage was as follows: R = +0.48 ± 0.01, and for soil protective technologies it was: R = (+0.70–75) ± 0.01. The increase in microaggregation in conditions of soil protective tillage occurs in the direction of wild land analogs and fallow, which testifies to the simulation of the natural process of typical chernozem microaggregation in the agrocenoses of the Left-Bank Forest-Steppe of Ukraine.

Мікроагрогенез чорнозему в агроценозі

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Мета досліджень полягала в науково-теоретичному обґрунтуванні процесу мікроагрегування чорноземів типових завдяки моделюванню природних процесів ґрунтотворення під впливом систематичного застосування ґрунтозахисних технологій вирощування сільськогосподарських культур з поверхневим загортанням кореневих, післяжнивних решток, гною і мінеральних добрив в агроценозах Лівобережного Лісостепу України. **Методи**. Лабораторно-аналітичний, експериментально-польовий, статистичний. **Результати**. При оранці (понад 75 років) кількість вільних- і рихлозв'язаних агрегатів у 0–40-см шарі чорнозему знижується до 17–20 %, а на фоні органо-мінеральної системи удобрення (15 т/га гною + $N_{80}P_{75}K_{60}$) підвищується вміст зазначених груп мікроагрегатів до 20–25 %. Систематичне виконання ґрунтозахисних технологій сприяє підвищенню вмісту вільних- і рихлов'язаних мікроагрегатів до 29–32 %. Коефіцієнт насиченості фізичної глини (ФГ) гумусом при оранці знижується порівняно з перелогом у 1.3–1.4 рази. Величина насиченості ФГ гумусом при ґрунтозахисному обробітку є оптимальною – гумус не накопичується у вигляді вільних гуматів, не відкладається як "жир" у тваринних організмах і не відбувається блокування елементів живлення вільними гуматами. Гумус виступає як з'єднувальна тканина, що сприяє покращенню водостійкості структури чорнозему на мікро- і макроагрегатному рівнях. Здатність чорноземів до агрегування визначається фактором дисперсності (ФД), який при оранці без внесення добрив сягає значень 12–14 %, а при внесенні добрив – 10 %, що свідчить про слабку ступінь мікроагрегування. При мінімальному обробітку на фоні органо-мінеральної системи удобрення ФД = 6–7 %, а під кінець ротації знижується до 3–5 %. **Висновки.** Посилення мікроагрегування при ґрунтозахисних технологіях пояснюється тим, що детрит і новоутворені гумусові речовини при оптимізації гідротермічних умов у сезонному циклі і знижених темпах мінералізації гумусу підвищують свою роль у формуванні органо-мінеральних комплексів. При оранці між кількістю мікроагрегатів розміром 0.01–0.25 мм і вмістом пептизованих гумусових речовин коефіцієнт кореляції складає: R = = +0.48±0.01, а при ґрунтозахисних технологіях: R = = (+0.70–0,75)±0.01. Підвищення мікроагрегування за умов ґрунтозахисного обробітку відбувається у напрямку цілинних аналогів і перелогу, що свідчить про моделювання природного процесу мікроагрегування чорноземів типових в агроценозах Лівобережного Лісостепу України.

Ключові слова: мікроагрегати, агрогенез, чорнозем, гумус, обробіток ґрунту.

Микроагрогенез чернозема в агроценозе

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Цель исследований заключалась в научно-теоретическом обосновании процесса микроагрегирования черноземов типичных благодаря моделированию природных процессов почвообразования под влиянием систематического применения почвозащитных технологий выращивания сельскохозяйственных культур с поверхностной заделкой корневых, послежатвенных остатков, навоза и минеральных удобрений в агроценозах Левобережной Лесостепи Украины. **Методы.** Лабораторно-аналитический, экспериментально-полевой, статистический. **Результаты.** При вспашке (более 75 лет) количество свободных- и рыхлосвязанных агрегатов в 0–40-см слое чернозема снижается до 17–20 %, а на фоне органо-минеральной системы удобрения (15 т/га навоза + $N_{80}P_{75}K_{60}$) содержание названных групп микроагрегатов повышается до 20–25 %. Систематическое выполнение почвозащитных технологий способствует увеличению содержания свободных- и рыхлосвязанных микроагрегатов до 29–32 %. Коэффициент насыщенности физической глины (ФГ) гумусом при вспашке снижается по сравнению с залежью в 1.3–1.4 раза. Величина насыщенности ФГ гумусом при почвозащитной обработке является оптимальной – гумус не накапливается в виде свободных гуматов, не откладывается как "жир" в животных организмах и не происходит блокировки элементов питания свободными гуматами. Гумус выступает как соединительная ткань, что способствует улучшению водостойкости структуры чернозема на микро- и макроагрегатном уровнях. Способность черноземов к агрегированию определяется фактором дисперсности (ФД), который при вспашке без внесения удобрений достигает значений 12–14 %, а при внесении удобрений – 10 %, что свидетельствует о слабой степени микроагрегированности. При минимальном возделывания на фоне органо-минеральной системы удобрения – ФД = 6–7 %, а под конец ротации снижается до 3–5 %. **Выводы.** Усиление микроагрегирования при почвозащитных технологиях объясняется тем, что детрит и новообразованные гумусовые вещества при оптимизации гидротермических условий в сезонном цикле и сниженных темпах минерализации гумуса повышают свою роль в формировании органо-минеральных комплексов. При пахоте между количеством микроагрегатов размером 0.01–0.25 мм и содержанием пептизированных гумусовых веществ коэффициент корреляции составляет $R = +0.48 \pm 0.01$, а при почвозащитных технологиях: $R = (+0.70–0,75) \pm 0.01$. Повышение микроагрегирования в условиях почвозащитной обработки происходит в направлении целинных аналогов и залежи, что свидетельствует о моделировании естественного процесса микроагрегирования черноземов типичных в агроценозах Левобережной Лесостепи Украины.

Ключевые слова: микроагрегаты, агрогенез, чернозем, гумус, обработка почвы.

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