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PARAMETERIZATION OF CHANGES IN SOIL ORGANIC CARBON CONTENT DEPENDING ON THE FERTILIZATION SYSTEM

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Goal. To determine the parameters of changes in the content of organic carbon in typical chernozem depending on the long-term use of different fertilizer systems for field crop rotation in the High Forest-Steppe of the Left Bank of Ukraine. **Methods.** Field — to determine the impact of fertilizer application systems on the humus state of typical chernozem, laboratory — to determine the content of organic carbon in the soil, calculation — to calculate the reserves of organic carbon and humus, mathematical — to assess the reliability of the data. **Results.** It was determined that before the establishment of a stationary field experiment, the content of organic carbon (Corg) in the arable soil layer averaged 2.89%. The coefficient of variation of theparameters of this indicator was 8%, but the scope of variation of the obtained results was 1.03 abs. %. It was established that for 28 years of application of mineral and organic fertilizers there was a slow deposition of Corg. Under the mineral fertilizer system with the introduction of single and double doses of complete fertilizer, the Corg content increased from 2.94 – 2.96 to 3.09 – 3.10%. Under the organic system, which provided the periodic application of manure under row crops, the Corg content increased from 2.80 to 3.09%, while the combined application of manure and mineral fertilizers caused an increase in Corg from 2.71 – 2.79 to 3.09 – 3.16%. Corg reserves increased from 5 for the mineral to 10 and 13 t/ha for organic and organomineral fertilizer systems, respectively. **Conclusions.** An increase in the Corg content in typical chernozem was established with the introduction of fertilizer systems in a row: mineral — +0.14 – 0.15 abs.%, organic — +0.29, organomineral — +0.37 – 0.38 abs.%. The systematic application of mineral and periodic of organic fertilizers contributes the most to carbon deposition in soils.
Key words: *soil organic matter, mineral and organic fertilizers, stationary field experiment, typical chernozem.*

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Among the wide range of indicators of soil quality, the greatest attention is paid to the content and stocks of soil organic carbon, which determine the level of soil fertility (productive function), its health and ability to implement ecosystem services [1, 2].

The concern of the world scientific community with the large-scale development of dehumidification processes led to the holding of the Global Symposium on Soil Organic Carbon under the auspices of FAO in March 2017, which was attended by more than 450 participants from 111 countries. Particular attention was paid to three key areas of potential activity, some of which are aimed at implementing the Global Sustainable Development Goals, which are relevant for Ukraine:

- ✓ measuring, mapping, control and reporting of changes in soil organic carbon stocks;
- ✓ promoting the accumulation of soil organic carbon to adapt to climate change and mitigate its effects, achieving land degradation neutrality;
- ✓ conservation/restoration of soil organic carbon stocks in particularly vulnerable locations [3].

An anthropogenic factor plays an exceptional role in determining the vector of changes in soil organic carbon, under the influence of which the course of such soil processes as humification and mineralization of humus is changed [4] and the degree of these changes depends on the genetic characteristics of the soil and hydrothermal conditions of the territory. Thus, the content of organic carbon in soils varies both from a specific element of the technology of growing crops, whether tillage, fertilization or crop rotation, and from the implemented land use system in general [5–9].

To compensate for the loss of soil organic matter, including due to the reduction of plant residues, which corresponds to economic removal, it is recommended to apply organic fertilizers, which play an exceptional role in preserving and increasing soil fertility [10–12]. Concerning the influence of mineral fertilizers, there are contradictory, diametrically opposed points of view. On the one hand, their incorporation (application), especially in high doses, causes dehumidification by increasing the content of humus mobile fractions [13]. With the use of balanced doses, in fact, there are no significant changes in the direction of reduction [14, 15]. Other studies indicate an increase in the total humus content with the iimplementation of a mineral fertilizer system, especially in combination with organic one [16, 17]. Also, it is noted that with long-term application of fertilizers there are changes in both quantitative and qualitative composition of the system of soil humic substances [18].

Thus, the controversy over the ambiguity of the impact of mineral fertilizers on the content and stocks of organic carbon maintains a constant interest in this issue, especially given the diversity of soil cover, the differences of weather and climatic conditions and agricultural systems.

The purpose of the work is to establish the parameters of changes in the organic carbon content in typical chernozem depending on the long-term use of different fertilization systems of field crop rotation in the Left-Bank High Forest-Steppe of Ukraine.

Materials and methods of research. The research is carried out in the stationary field experiment «Agroecological monitoring» within the State Enterprise «Experimental Farm «Grakivske» of the National Scientific Center «Institute for Soil Science and Agrochemistry Research named after O. N. Sokolovsky», which is territorially located near the Doslidne village of Chuguiv district of Kharkiv region. The experiment was established in 1990 in three fields of 3.5 ha each, after leveling sowing of barley, according to a mathematically sound scheme. The size of the elementary experimental plot is 120 m^2 (20 m × 6 m), the epetitiveness of options in space is four times. The research results are given by the first field.

Within the field, backgrounds are formed, which are aimed at creating a model of soil fertility with different energy intensity. Within each background, there are 15 options with combinations of mineral fertilizer rates in three grades: 0 – without fertilizers, 1 – single, 2 – double, which are differentiated by crop rotation. For example, for winter wheat N = 0–45–90, P = 0–45–90, K = 0–45–90; for corn for silage N = 0–90–180, P = 0–60–120, K = 0–45–90; for sunflower N = 0–45–90, P = 0–55–110, K = 0–45–90.

From the general set of experiment options for implementation of the purpose the following options are allocated:

- ✓ without fertilizer application: I background (without organic fertilizer application) + 000;
- ✓ mineral fertilizer system: I background (without organic fertilizers) + 111, 222;
- ✓ organic fertilizer system: II background (manure application) + 000;
- ✓ organo-mineral fertilizer system: II background (manure application)+ 111, 222.

The total amount of nutrients applied with mineral fertilizers for the period 1990–2018, with a single rate (111) is $N_{1395}P_{1340}K_{1170}$, with a double rate (222) – $N_{2790}P_{2680}K_{2340}$. A total of 230 t/ha of manure was applied.

Since 1991, studies have been conducted in twelve-course I rotation) and ten- course (II rotation) field crop rotation. Since 2013, the third rotation of the nine-course crop rotation has begun: sunflower, black steam, winter wheat, barley, soybeans, winter wheat, corn green mass, naked oat, winter wheat.

The soil cover of the research area is represented by typical heavy loamy chernozem, which before the start of the experiment was characterized by a very high degree of base saturation – 96–98 %. The amount of exchange-absorbed bases in the areas under the future mineral fertilizer system, on average, was 46.5 mg-eq/100 g of soil, under the organo-mineral one – 48.8 mg-eq/100 g of soil, of which the share of exchangeable calcium – 89 and 90 % respectively. Exchangeable acidity (pH_{KCl}) of the soil corresponded to Land Degradation Neutrality. According to the content of mobile phosphorus compounds, the soil was characterized by an average level of availability. The content of mobile potassium compounds corresponded to the increased availability.

Soil samples for analysis were taken from the arable 0–30 cm layer according to DSTU 4287: 2007 before starting the experiment in 1990, at the end of the second rotation after soybean in 2011 and in the middle of the third rotation after wheat in 2018. The content of soil organic carbon (SOC) in the prepared soil samples was determined according to DSTU 4289: 2004.

Processing and generalization of research results was performed using the programs: STATISTICA and Microsoft EXCEL.

Research results and their discussion. It is believed that changes in the intensity of accumulation and mineralization of SOC can be reliably determined only in long-term field experiments [19]. However, when summarizing the results of long-term research on such high-buffer soils as chernozem, the main thing is not to confuse the natural temporal dynamics of the studied indicator with its direct changes under the influence of one or another anthropogenic factor.

At the type level, typical heavy loamy chernozem at the time of the experiment was characterized as medium humus. The content of SOC in the arable 0–30 cm layer of soil under the future mineral fertilization system averaged 2.96 %. In the area where organic fertilizers were applied, it ranged from 2.49 % to 3.24 %, averaged 2.83 %. In general, on the area of 2 ha, covering the I and II background, a low heterogeneity of this parameter was found – the coefficient of variation does not exceed 8 % (Table 1). However, with the same qualitative characteristics, which are estimated as high (4.1–5.0 %) according to the domestic grouping of soils by humus content, the range of variation of the averaged data by options (four repetitiveness in space) is 1.03 absolute percent. This gives grounds to speak about the presence of lateral heterogeneity of soil cover within the elementary soil area (one soil allocation) [20], which should be taken into account when establishing changes in soil parameters in spatial and temporal context to avoid misinterpretation of long-term results.

1. Statistical parameters of soil organic carbon content determined before the experiment

Statistical parameter	Without application of organic fertilizers (I background)	On the application background of organic fertilizers (II background)	In general, under the I and II background
Number of mixed samples, pcs	76	76	152
% suitable definitions	100	100	100
Medium	2.96	2.83	2.89
Minimum	2.37	2.49	2.37
Maximum	3.39	3.24	3.39
Range	1.03	0.75	1.03
Median	3.01	2.85	2.89
Standard error	0.03	0.02	0.02
Standard deviation	0.24	0.20	0.23
Lower quartile (25 %)	2.78	2.67	2.69
Upper quartile (75 %)	3.15	2.98	3.07
Coefficient of variation	8.20	6.97	7.93

During the 28-years (from 1990 to 2018) of regular use of mineral fertilizers and periodic application of manure, there is a clear trend towards gradual deposition of SOC in typical chernozem (Fig. 1), as evidenced by previous studies of humus changes in the 19-years interval [21]. In particular, the control option recorded an increase in the content of SOC by 1.7 %, while the application of single rates of mineral fertilizers with a total amount of $N_{1395}P_{1340}K_{1170}$ increases its content by 5.1 %, with the application of double standards with which came to the ground $N_{2790}P_{2680}K_{2340}$ – 4.7 %. With the organic fertilizer system, where 230 t/ha of manure have been applied in 28 years, the SOC content is increased by 10.4 %, while the combination of manure and mineral fertilizers causes an increase of 13.3–14.0 %, reaching 3, 09–3.16 % SOC as a part of soil organic matter. The difference in the content of SOC between the unfertilized arable land and with the organo-mineral fertilizer system is 0.32–0.33 absolute percentages (Table 2).

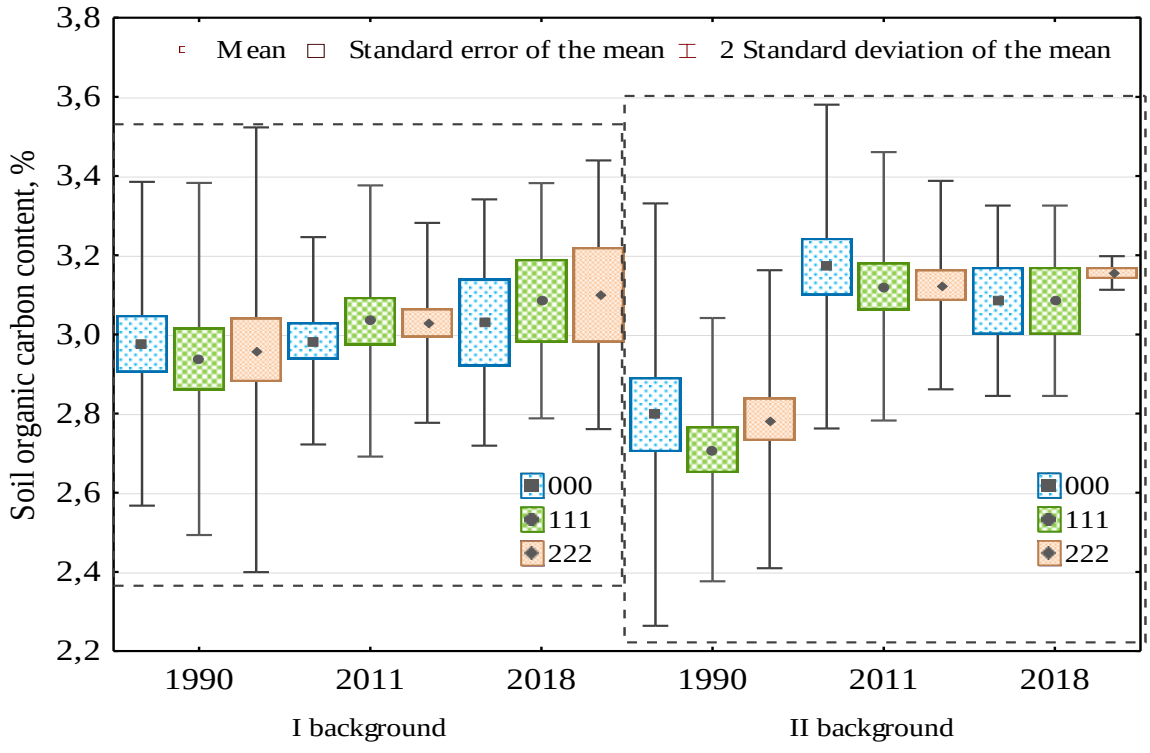

Fig. 1. Changes in the content of SOC in typical chernozem with the application of mineral and organic fertilizers during 28 years

The above-mentioned regularities are also preserved in the increased stocks of SOC, which reach a maximum of 105–107 t/ha in the 0–30 cm soil layer with organic and organo-mineral fertilizer systems. Given the existing direct relationship between SOC and total humus, there is an increase in the content and stocks of total humus, due to the use of scientifically sound technologies for growing crops in crop rotation, among which the key factor influencing the deposition of organic matter is the implemented fertilizer application system (Table 2). In addition, the prevention of SOC losses ensures the resistance of the soil to significant changes in the reaction of the soil environment and indirectly affects the formation of high agrobackgrounds.

It should be noted that with the implementation of similar fertilizer systems for 26 years, but on typical chernozem, which is characterized as highly moist deep carbonate one (according to the soil survey of the State Enterprise «Experimental Farm «Grakivske» of the National Scientific Center «Institute for Soil Science and Agrochemistry Research named after O. N. Sokolovsky» in 2017 year), there are no changes in the main parameters of humus quality – the type of humus is characterized as purely humic, the degree of humification as high [22].

2. Growth of SOC content and stocks of total humus in typical chernozem for the period 1990–2018

Background	Option	Content growth for the period 1990–2018, absolute percentages		SOC stocks in 0–30 cm of soil layer, t/ha		Increase of humus stocks for 28 years, t/ha
		SOC	total humus	1990	2018	
Without application of organic fertilizers	000	0.05	0.09	101	103	3.1
	111	0.15	0.25	100	105	8.6
	222	0.14	0.24	100	105	8.1
On the application background of organic fertilizers	000	0.29	0.50	95	105	16.8
	111	0.38	0.65	92	105	22.0
	222	0.37	0.64	95	107	21.6

Thus, there is no loss of SOC for 28 years of systematic application of single and double rates of mineral fertilizers under field crop rotation crops. Compared with the initial parameters of the SOC content in typical chernozem, there is a tendency to its growth with the implementation of fertilizer systems in a row: mineral - organic - organo-mineral. Accordingly, the most effective measure to improve the humus state of the soil and increase the amount of SOC deposition is the organo-mineral fertilizer system, which provides for regular application of mineral fertilizers and for periodic one- organic fertilizers. Our foreign colleagues came to similar conclusions with generalizing the results of long-term experiments, omitting the difference of absolute quantitative values [16, 17, 23, 24]. This indicates that the balanced application of mineral and organic fertilizers helps to maintain and improve soil quality in the long run [17].

It should be noted that with a number of research on humus content and carbon in the soil organic matter, it was found a significant increase in mineralization processes with long-term implementation of the mineral fertilizer system [25, 26]. In our case, the absence of dehumidification is explained by the peculiarities of evolutionary changes in old arable soils, the identification of which requires quite a long time. It is known that the most significant changes in qualitative and quantitative indicators occur in the first decades after the plowing of virgin soils [25, 27, 28]. Then, after a certain period of time, the soil comes to a state of indefinitely long dynamic equilibrium (quasi-equilibrium) with the environment, the stability of which is provided in a wide range of variations of external conditions (load) [29].

Given the fact that on the typical chernozem, where the stationary field experiment was laid, extensive agriculture was conducted during more than 73 years, after plowing virgin land and subsequent extensive use there was the most significant decrease in the SOC content. Thus, in 1990 the total humus content was 4.9–5.1 % (or 2.83–2.96 % of SOC), which with a high probability characterizes the quasi-equilibrium state of the soil, while in the typical chernozem of the surrounding areas under natural vegetation – 6.3 % [30] (or 3.65 % of SOC), which can be taken as the content of total humus in virgin soil. Accordingly, during the agricultural use of the soil until 1990, the content of SOC decreased by 19–22 % or 0.69–0.82 absolute units and stabilized at this level.

After the replacement of extensive technologies with science-based cultivation of agricultural crops with fertilizers` application, the soil is moving to a higher energy level – the soil has become «cultivated», as evidenced by the tendency to increase the humus content, while irrational land use reduces the energy of the soil system, causing the development of degradation processes [31].

Conclusions

Under conditions of stationary field experiment, changes in the parameters of SOC content in typical chernozem were established, which depend on the fertilization system of field crop rotations. In the 28-years retrospective there is a clear tendency to the gradual accumulation of SOC, the content of which increases with the implementation of fertilizer systems in a row: mineral + 0.14–0.15 absolute percentages, organic + 0.29 absolute percentages and organo-mineral + 0,37–0.38 absolute percentages. Systematic application of mineral fertilizers and periodic application of organic ones contributes the most to carbon deposition in the soil.

References

1. Cardoso, E. J. B. N., Vasconcellos, R. L. F., Bini, D. et al. (2013). Soil health: looking for suitable indicators. What should be considered to assess the effects of use and management on soil health? *Scientia Agricola*, *70(4),* 219–303. doi: 10.1590/S0103-90162013000400009
2. Lal, R. (2016). Soil health and carbon management. *Food and Energy Security, 5(4),* 212–222. doi: 10.1002/fes3.96
3. Unlocking the Potential of Soil Organic Carbon – Outcome Document of the Global Symposium on Soil Organic Carbon. (2017, March 21–23). Rome: FAO. (36 p.) URL: http://www.fao.org/3/I7268EN/i7268en.pdf
4. Degtayrov, V. V., Morgunova, O. I. & Nedbaev, V. N. (2013). Izmenenie soderzhaniya gumusa i azota v chernozemah Ukrainyi v zavisimosti ot antropogennogo vozdeystviya na pochvyi [Change in the content of humus and nitrogen in chernozems of Ukraine depending on anthropogenic impact on soils]. *Vestnik of Kursk State Agricultural Academy*, *6*, 9–15. [In Russian].
5. Hao, Y. J., Wang, Y. H., Chang, Q. R. & Wei, X. R. (2017). Effects of long-term fertilization on soil organic carbon and nitrogen in a highland agroecosystem. *Pedosphere*, *27(4),* 725–736. doi: 10.1016/S1002-0160(17)60386-2
6. Ghimire, R., Lamichhane, S., Acharya, B. S. et al. (2017). Tillage, crop residue, and nutrient management effects on soil organic carbon in rice-based cropping systems: A review. *Journal of Integrative Agriculture, 16(1),* 1–15. doi: 10.1016/s2095-3119(16)61337-0
7. *Mehra, P., Baker, J., Sojka, R. E.* et al. (2018). A Review of Tillage Practices and Their Potential to Impact the Soil Carbon Dynamics. *Advances in Agronomy, 150,* 185–230. doi: 10.1016/bs.agron.2018.03.002
8. Zuber, S. M., Behnke, G. D., Nafziger, E. D. & Villamil, M. B. (2018). Carbon and nitrogen content of soil organic matter and microbial biomass under long-term crop rotation and tillage in Illinois, USA. *Agriculture, 8(3), Art. 37.* (12 p.) doi: 10.3390/agriculture8030037
9. Shatsman, D. O., Pinchuk, V. O., Mostoviak, I. I. & Demyanyuk,O. S. (2019). Zmina pokaznykiv rodiuchosti chornozemu typovoho za bezzminnoho vyroshchuvannia kukurudzy [Change in the typical black fertility indicators for the conversional growing of maize]. *Balanced nature using, 3,* 43–52. doi: 10.33730/2310-4678.3.2019.185882 [In Ukrainian].
10. Skrylnik, E. V., Kutovaya, A. N., Hetmanenko, V. A. & Tovstiy, Iu. N. (2016). Yakist mistsevoi syrovyny riznoho pokhodzhennia ta shliakhy yikh ratsionalnoho vykorystannia u silskomu hospodarstvi [The quality of local raw materials of different origin and ways oftheir rational use in agriculture]. *Bulletin of Agricultural Science, 7,* 12–17. doi: 10.31073/agrovisnyk201607-02 [In Ukrainian].
11. Li, S., Li, J., Li, G. et al. (2017). Effect of Different Organic Fertilizers Application on Soil Organic Matter Properties. *Compost Science and Utilization, 25(1),* 31–36. doi: 10.1080/1065657X.2017.1344160
12. Zhao, Z., Zhang, C., Li, F. et al. (2020). Effect of compost and inorganic fertilizer on organic carbon and activities of carbon cycle enzymes in aggregates of an intensively cultivated Vertisol. *PLoS ONE, 15(3). Art. e0229644.* doi: 10.1371/journal.pone.0229644
13. Chekmarev, P. A., Obuschenko, S. V. & Trots, N. M. (2013). Vliyanie sistemnogo primeneniya mineralnyih udobreniy na soderzhanie gumusu v chernozeme obyiknovennom [Influence of systemic application of fertilizers on the humus content in the ordinary chernozem]. *Achievements Of Science & Technology Of AICis, 6,* 32–34. [In Russian].
14. Miroshnychenko,M. M., Hladkikh, Ye. Iu. & Revtie, A. V. (2016). Zminy yakosti ta rodiuchosti gruntu za zastosuvannia bezvodnoho amiaku v zemlerobstvi [Changes of quality and fertility of soil at the application of anhydrous ammonia in agriculture]. In M. M. Miroshnychenko (Ed.). *Teoriia i praktyka gruntookhoronnoho monitorynhu* [Theory and practice of soil-protective monitoring] (pp. 247–282). Kharkiv: FOP Brovin O. V. [In Ukrainian].
15. Singh. B. (2018). Are Nitrogen Fertilizers Deleterious to Soil Health? *Agronomy, 8(48),* 19. doi: 10.3390/agronomy8040048
16. Wei, W., Yana, Y., Cao, J. et al. (2016). Effects of combined application of organic amendments and fertilizers on crop yield and soil organic matter: An integrated analysis of long-term experiments. *Agriculture, Ecosystems and Environment*, *225,* 86–92 doi: 10.1016/j.agee.2016.04.004
17. Mensik, L., Hlisnikovsky, L. & Kunzova, E. (2019). The state of the soil organic matter and nutrients in the long-term field experiments with application of organic and mineral fertilizers in different soil-cli-mate conditions in the view of expecting climate change. *Organic fertilizers – history, production and applications.* In M. L. Larramendy, S. Soloneski (Eds.). doi: 10.5772/intechopen.86716

18. Skrylnik. Ye. V. (2016). The impact of different fertilization systems on content, composition, energy intensity of organic matter in chernozem soil. *Agricultural science and practice, 2,* 49–55. https://doi.org/10.15407/agrisp3.02.049
19. Janzen, H. H. (2009). Long-term ecological sites: musings on the future, as seen (dimly) from the past. *Global Change Biology, 15,* 2770–2778. doi: 10.1111/j.1365-2486.2009.01971.x
20. Medvedev, V. V. (2010). Neodnorodnost kak zakonomernoe proyavlenie gorizontalnoy strukturyi pochvennogo pokrova [Heterogeneity as natural display of horizontal structure of a soil cover]. *Soil Science, 11(1–2)*, 6–15. [In Russian].
21. Skrylnik, E. V. (2010). Transformatsiia humusovoho stanu gruntiv ta yikh enerhoiemnosti pid vplyvom riznykh system udobrennia [Transformation of humus soil condition and their energy intensity under the influence of different fertilizer systems]. *Bulletin of the Center for Science Provision of Agribusiness in the Kharkiv region, 7,* 184–194. [In Ukrainian].
22. Skrylnik, E. V., Kutovaya, A. N., Hetmanenko, V. A. et al. (2019). Vplyv system udobrennia na orhanichnu rechovynu ta ahrokhimichni pokaznyky chornozemu typovoho [Influence of fertilizers application systems on soil organic matter and agrochemical characteristics of the chernozem typical]. *Agrochemistry and Soil Science, 88,* 74–78. doi: 10.31073/acss88 [In Ukrainian].
23. Paramonov, A. V., Fedyushkin, A. V., Pas'ko, S. V. & Medvedeva, V. I. (2018). Vliyanie sistematicheskogo primeneniya udobreniy v devyatipolnom zernoparopropashnom sevooborote na balans gumusa v chernozeme obyiknovennom [Influence of Systemic Application of Fertilizers in a Nine-Field Crop Rotation on Humus Balance in Ordinary Chernozem]. *Achievements Of Science & Technology Of AICis*, *32(9),* 9–11. doi: 10.24411/0235-2451-2018-10902 [In Russian].
24. *Guo, Z., Zhang, Z., Zhou, H.* et al. (2019). The effect of 34-year continuous fertilization on the SOC physical fractions and its chemical composition in a Vertisol. *Scientific Reports, 9, Art. 2505*. doi: 10.1038/s41598-019-38952-6
25. Muha, V. D. (2004). Osnovnyie zakonomernosti kulturnogo pochvoobrazovaniya [Basic laws of cultural soil formation]. *Bulletin of Kharkiv National Agrarian University named after V. V. Dokychaiev, 1,* 39–44. [In Russian].
26. Mensik, L., Hlisnikovsky, L., Pospisilova, L. et al. (2018). The effect of application of organic manures and mineral fertilizers on the state of soil organic matter and nutrients in the long-term field experiment. *Journal of Soils and Sediments*, *18*, 2813–2822. doi: 10.1007/s11368-018-1933-3
27. Nosko, B. S. (2006). Antropohenna evoliutsiia chornozemiv [Anthropogenic evolution of chernoze]. Kharkiv: «13 typohrafiia» (239 p.). [In Ukrainian].
28. Tyhonenko, D.G. (2012). Evoliutsiia i klasyfikatsiia ahrohennykh gruntiv Ukrainy [Evolution and classification of agrogen soils in Ukraine]. *Biological systems, 4(1),* 96–99. [In Ukrainian].
29. Smagin, A. V., Sadovnikova, N. B., Smagina, M. V. et al. (2001). Modelirovanie dinamiki organicheskogo veschestva pochv [Modeling the dynamics of soil organic matter]. Moskva: Izd-voMGU. (120 p.). [In Russian].
30. Pochvyi Ukrainyi i povyishenie ih plodorodiya. T. 1: ekologiya, rezhimyi i protsessyi, klassifikatsiya i genetiko-proizvodstvennyie aspektyi (1988). [Soils of Ukraine and increasing their fertility. Volume 1: ecology, regimes and processes, classification and genetic-production aspects]. In N. I. Polupana (Ed.). Kiev: Urozhay. (pp. 94–103). [In Russian].
31. Ramesh, T., Bolan, N. S., Kirkham, M. B. et al. (2019). Soil Organic Carbon Dynamics: Impact of Land Use Changes and Management Practices: a Review. *Advances in Agronomy, 156,* 1–107. doi: 10.1016/bs.agron.2019.02.001