Agraarteadus
1 • XXXIII • 2022 192–198

Journal of Agricultural Science
1 • XXXIII • 2022 192–198

CHANGES IN THE NITROGEN COMPOUND TRANSFORMATION PROCESSES OF TYPICAL CHERNOZEM DEPENDING ON THE TILLAGE SYSTEMS AND FERTILIZERS

Oleksiy Tsyuk[1], Mykola Tkachenko[2], Andrii Butenko[3], Yurii Mishchenko[3], Iryna Kondratiuk[2], Dmytro Litvinov[1], Yuliia Tsiuk[4], Yurii Sleptsov[1]

[1]National University of Life and Environmental Sciences of Ukraine, 15 Heroiv Oborony, Kyiv, 03041, Ukraine
[2]National Scientific Center, Institute of Agriculture of NAAS, Kyiv, Ukraine
[3]Sumy National Agrarian University, 160 H. Kondratieva St., UA40021, Sumy, Ukraine
[4]Central Testing State Laboratory of the State Food with Consumer Service in Kyiv region and Kyiv, 26 Balukova St., Vyshneve, Kyiv region

Saabunud: Received: 15.12.2021

Aktsepteeritud: Accepted: 18.06.2022

Avaldatudveebis: Published online: 18.06.2022

Vastutavautor: Corresponding author: Andrii Butenko

E-mail: andb201727@ukr.net

ORCID:
0000-0001-8789-522X (OT)
0000-0001-6128-4703 (MT)
0000-0001-9639-9826 (AB)
0000-0002-5942-9288 (YM)
0000-0002-8953-8194 (IK)
0000-0001-6589-3805 (DL)
0000-0003-3240-8564 (YT)
0000-0002-3412-7320 (YS)

Keywords: typical chernozem, soil microcoenosis, fertilizers, tillage, mineralization-immobilization coefficient.

DOI: 10.15159/jas.22.23

ABSTRACT. The analysis of efficiency's research of interrelation between soil's biomass and tillage systems and fertilizers is done. The number of microorganisms responsible for the transformation of nitrogen compounds and their state in typical black soil was studied. There is evidence-based scientific and practical research on the effectiveness of these microbiological processes and the improvement of environmental performance through the various fertilizer systems and soil tillage. The use of an organic-mineral fertilizer system increases the total number of soil microorganisms and exponential mobilization processes, compared to the variant without fertilizers. This pattern is clear in the variants of shelf tillage for row crop rotation. The number of microorganisms that absorb mineral compounds of nitrogen decreased by 24%, bacteria ammonification by 1.5–5.7% compared to plough tillage. The ratio between the number of microorganisms accounted for the nutrient laboratory solutions for organic-mineral fertilizer system, compared to variants without fertilizers, is greater by 20–26% for differentiated and 14–35% for shallow tillage.

Introduction

Soil biological activity, especially soil enzymatic activity, respiration process and microbial biomass, is related to various soil factors, including pH, soil organic matter, texture and modifying factors such as climate, humidity and soil temperature. (Emmerling *et al.*, 2001; Bastida *et al.*, 2008). Microbial biomass, metabolic rate (CO_2, respiratory activity index per unit of biomass, CO_2-C/MBC) and soil enzymatic activity may be used as indicators of soil changes (Ros *et al.*, 2003; Bastida *et al.*, 2008). Enzymes are formed with soil microorganisms and, despite their relatively low number, have a crucial role in providing the nutrient cycle in soils such elements as C, N, P and S. Nutrient cycling is fundamental for the long-term functioning of ecosystems. In addition, soil microbial activities, microbial biomass, and soil AT acid content have been proven indicators of soil quality (Bending *et al.*, 2004; Goberna *et al.*, 2006; Bastida *et al.*, 2008). Soil

microbial activity is a sensitive indicator of soil agricultural practices, the input of fertilizers, organic matter and crop rotation (Emmerling *et al.*, 2001; Bending *et al.*, 2004).

The application of a balanced amount of fertilizers and manures could increase enzymatic activity and soil respiration (Kanchikerimath, Singh, 2001). Organic fertilizers usually increase soil microbial biomass (Liang *et al.*, 2005; Kaur *et al.*, 2005). Organic manure-stimulated biological activity and soil microbial biomass have been proven to be positively correlated with improved soil fertility and quality as indicated by higher crop biomass and higher concentration of soil available nutrients and plant nutrient uptake (Bending *et al.*, 2004; 2005; Tu *et al.*, 2006; Kaminskyi *et al.*, 2021). Furthermore, these biological parameters can be used as sensitive bio-indicators of soil nutrient transformation, biological turnover and bio-availability (Tu *et al.*, 2006). Long-term use or overuse of organic fertilizers had a relatively less positive effect on soil microbial biomass and activities than organic fertilizers (Hopkins, Shiel, 1996; Plaza *et al.*, 2004; Hryhoriv *et al.*, 2021). Numerous studies showed that microbial biomass could be decreased by the application of mineral N fertilizer (Hopkins, Shiel, 1996; Sarathchandra *et al.*, 2001; Bittman *et al.*, 2005), which may be caused by direct toxicity and reduced pH because of ammonium-based fertilizers (Hopkins, Shiel, 1996).

In the scientific works of Ukraine's scientists (Andreyuk, 2001; Tsyuk, 2018) the theoretical bases of the formation of soil's structure and the functioning of their microbic cenoses (Patika *et al.*, 2014, 2015) are devoted to researching the elements of formation of microbic groups in agrocenoses and application of microbial solutions as well (Bilyavskaya *et al.*, 2010).

In black soils, the total number and species composition of microorganisms depend on weather and climatic conditions, crops, *e.g.* the level of application of mineral fertilizers and plant protection products and agronomic tillages. Changes in the degree of influence of these factors on the soil are affected by the activity of the microflora and the products of its metabolism (Demyanyuk, 2016, 2018a,b,c).

The information available in the scientific literature are different and indicates that the role of growing crops in the regulation of soil biodynamics has not been studied enough. It can be stated the effect of technologies for growing crops on the soil's microbial population is sophisticated. To avoid negative consequences, it's necessary to concentrate more attention on this question.

However, despite the great amount of theoretical and methodological investigations, some questions about the transformation processes of nitrogen compounds on deep typical black soil is too little studied.

Our research aimed to estimate the changes in the number of microorganisms, and the direction of the mineralization processes intensity of typical black soil for different soil's tillage and fertilizers.

Materials and Methods

The experimental part of the scientific work was performed in the research field of the National University of Life and Environmental Sciences of Ukraine (2014–2020).

Table 1. Soil's capacities (mechanical, chemical)

Soil's type	Content					
	Humus, %	Light hydrolyzed nitrogen (by Cornfield), mg 100 g^{-1} soil	P (by Chirikov), mg 100 g^{-1} soil	Cationic-change K, mg 100 g^{-1} soil	Soil's density, g $cm^{3\,-1}$	pH
Black soil typical, deep big cloggy medium-loam on the loess	4.6–4.8	14.4	15.2	15.2	1.24	6.4

The scheme of crop rotation in the field was 1–2. Alfalfa, 3. Winter wheat, 4. Sugar beets, 5. Barley, 6. Soybeans, 7. Winter wheat, 8. Corn for silage, 9. Winter wheat, 10. Sunflower. This crop rotation uses three levels of fertilizer per 1 ha of crop rotation area:

- for the mineral system – compost 4.5 tonnes + $N_{80}P_{96}K_{108}$;
- organic-mineral system – compost 4.5 tonnes + $N_{40}P_{48}K_{54}$ + 3.5 tone by-products and green manure and organic-compost 4.5 t + 3.0 tone of secondary products and green mass.

The experiment used fertilizers: compost, ammonium nitrate, granular superphosphate and potassium chloride. The second factor studied was the system of basic tillage: 1) differentiated tillage (control), which is recommended in the Forest-Steppe zone. It provides five ploughs for crop rotation, two surface tillage for winter wheat at 10–12 cm after soybeans and corn for silage and one chisel tillage under barley at 20–22 cm; 2) Plough with unplough system that provides two ploughs for crop rotation under sugar beets at 28–30 cm and sunflower at 25–27 cm and unplough cultivation for other crops; 3) surface unplough tillage at 10–12 cm for all crops. Our investigations were held in the biocenosis of winter wheat after alfalfa.

The plot area was 240 m^2 with four times repetitions. Soil samples were taken up to deep 20 cm. The number of microorganisms was determined by the methods of sowing soil suspension on solid nutrient solutions (Iutinskaya, 2006). Meat-peptone agar was used to account for the number of nitrogen-absorbing bacteria in organic compounds; on starch-ammonia agar – the number of bacteria that assimilate mineral forms of nitrogen (Zvyagintsev, 1991). The direction of micro-

biological processes in the soil was determined by the methods described by Volkogon (2010b).

Statistical analysis of the results was performed using Statistica 6 software.

Results and Discussion

The functioning of microbial complexes in the soil provides continuous processes of transformation of organic matter in terrestrial ecosystems. The study of the dynamics of their numbers makes it possible to reveal the mechanisms that determine the general directions of the soil's matter transformation and the state of ecosystems in general (Patika *et al.*, 2010; Loboda *et al.*, 2019).

The number of soil microorganisms of different ecological and trophic groups in typical black soils and their ratio varies depending on the system of tillage and fertilizer.

It was found that in variants with different tillage systems, independently of the applied mineral fertilizers, a biologically different tillage layer of the soil is formed, in some parts of the arable layer the microorganisms are unevenly distributed. There is a decrease in the number of all groups of microorganisms down the soil profile, which is associated with changes in thermal, air and nutrient regimes, as well as an increase in soil density with depth.

The influence of the systems of the basic autumn processing of the soil on the microbiocenosis of the typical black soil showed itself differently. Unplough processing stimulates the rapid development of soil microorganisms in the upper 0–10 cm soil layer compared with plough processing, but not in the deeper layers.

Intensive technologies for growing crops, based on plough cultivation with the use of high rates of mineral fertilizers and plant protection chemicals, significantly change the taxonomic structure of microbial associations and their functional activity. The biological cycle of substances and energy are increased with soil's biological activity, increasing the mineralization of organic matter according to maintaining the level of humification processes (Sherstoboeva, 2017; Rieznik *et al.*, 2021). So in modern agrocenoses, there is a degradation of humus and a decrease in soil fertility (Saiko, 2002). The use of unplowed tillage with the saving of stubble and plant remains on the soil surface in combination with organic and mineral fertilizers, is accompanied by the formation of favourable conditions for microbiological processes and especially humus accumulation. According to (Balaev, Tonhka, 2013; Manko *et al.*, 2019), the humification coefficients of plant residues are increased by 20–30% together with unplowed cultivation and the processes of their mineralization are attenuated compared to ploughed cultivation.

Another approach is held Nikiforenko (1982), who believes that unploughed tillage reduces microbiological activity in the soil, changes the group composition of microorganisms, reduces the number of nitrifications organisms and deteriorates the conditions of plant's mineral nutrition.

Thus, in the variants without fertilizers, the number of microorganisms using mineral forms of nitrogen (potassium ammonium nitrate) increased by 27%, and on the organic-mineral by 1.6 times (Fig. 1).

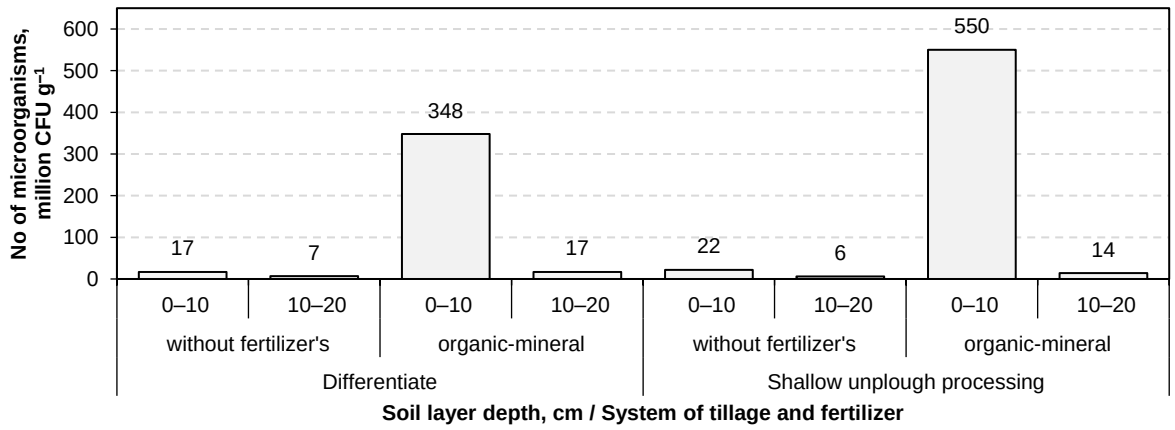

Figure 1. The number of microorganisms (million CFU g^{-1} of absolutely dry soil) of the main ecological and trophic groups in terms of application of the system of tillage and fertilizer (2014–2020 years) ($LSD_{0.05}$ for tillage – $F_f<F_{0.05}$; $LSD_{0.05}$ for fertilizers – 0.1; $LSD_{0.05}$ for soil's layer – 0.15)

Similar indicators were obtained for bacteria using nitrogen of organic compounds. The increase in their number, depending on the ground of fertilizer, was, respectively 1.5 and 1.7 times. In the case of unplough small tillage, the 0–10 cm layer remained richer in microorganisms throughout the growing season, due to the dominance of the plant residues on it, organic and mineral fertilizers, as well as better temperature conditions, higher moisture supply and good access to oxygen (Fig. 2).

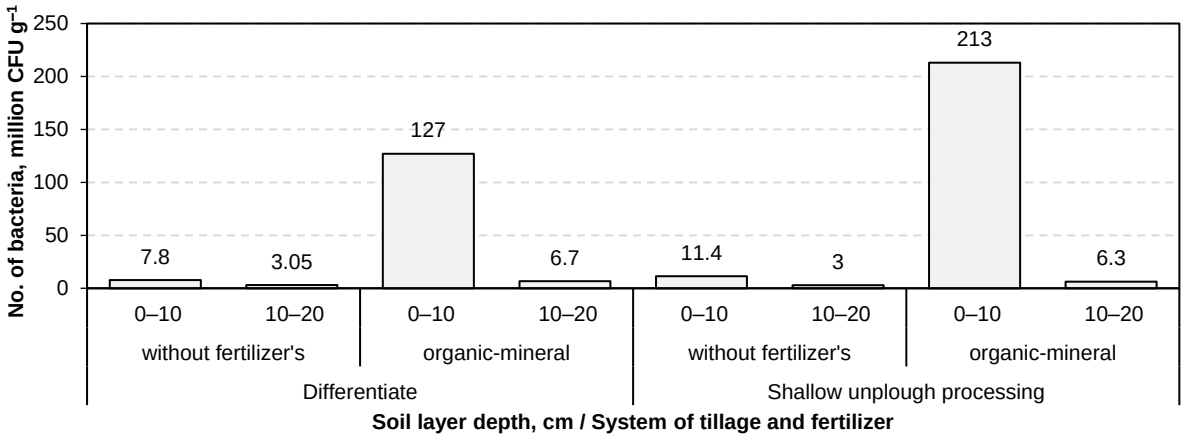

Figure 2. The number of bacteria (million CFU g^{-1} of absolutely dry soil) of the main ecological and trophic groups in terms of application of the system of tillage and fertilizer on 2014–2020 years ($LSD_{0.05}$ for tillage – $F_f<F_{0.05}$; $LSD_{0.05}$ for fertilizers – 1.12; $LSD_{0.05}$ – 1.14 for soil's layer)

It's necessary to note in terms of unploughed system the lower part of the treated layer is somewhat more microflora. Our research has shown a decrease in the number of microorganisms that absorb nitrogen mineral compounds by 9–24% and ammonifying bacteria – by 1.5–5.7% compared to plough processing.

The effect of fertilizers on the soil's microbial grouping was much stronger than the effect of soil's tillage. Their effect both during ploughing and unploughed tillage was observed in all parts of the treated layer, with a maximum at a depth of 0–10 cm. Under the influence of organo-mineral fertilizers, the number of microorganisms using mineral forms of nitrogen changed most significantly (1.5–2.0 times). As for bacteria using nitrogen of organic compounds, their number has decreased.

The organic-mineral fertilizer system increases the number of microorganisms in the soil and creates favourable mobilization processes compared to the variant without fertilizers. This is clear to both variants for processing at the depth of the treated layer.

The dynamics of the number of microorganisms in the main groups indicate the direction of microbiological processes toward degradation or restoring soil fertility. Microbiological processes occurring in black soils typical of the coefficient of mineralization-immobilization of nitrogen compounds were evaluated (Table 2). This coefficient characterizes their intensity and direction (Andreyuk, 2001; Parkhomenko *et al.*, 2021*).*

Table 2. The intensity of mineralization processes of typical deep black soil

System of soil's tillage	Fertilizer systems	Soil layer, cm	Nitrogen mineralization-immobilization coefficient
Differentiate (control)	Without fertilizer	0–10	2.18
		10–20	2.04
	Organic-mineral	0–10	2.74
		10–20	2.44
Shallow unplough processing	Without fertilizer	0–10	1.91
		10–20	1.87
	Organic-mineral	0–10	2.57
		10–20	2.15

The enhancement of mobilization processes on fertilized variants can also be judged from the ratio between the number of microorganisms recorded on potassium ammonium nitrate and MPA. According to our data, on fertilized variants, compared to variants without fertilizers, its value is higher by 20–26% for shelf cultivation and by 14–35% for shallow cultivation. According to our investigations, on fertilized variants, compared to variants without fertilizers, its value is higher by 20–26% for shelf cultivation and by 14–35% for shallow cultivation.

As for the absolute values of mineralization-immobilization coefficients, their value, independently of the agrochemical ground, is 3–13% less than shallow tillage.

Microbiocenosis, formations in black soil typical for the variant from differentiated processing is increased the process of mineralization, due to the mineralization of organic matter, and a small unploughed processing is inhibit this process. It pleases with the thought (Andreetta *et al.*, 2011) obtained results on the content and reserves of total humus.

On typical deep soils with a low buffering capacity, it is impractical to apply high rates of mineral fertilizers, which causes a significant imbalance of microbiocenosis and does not contribute to the preservation of organic matter (Volkogon *et al.*, 2010a).

Conclusion

A study of the impact of the transformation of nitrogen compounds of chernozem typical of tillage and fertilizer systems showed that without the use of fertilizers microorganisms that use mineral forms of nitrogen, their number increased by 27%, and the organo-mineral system – by 1.6 times. There was a decrease in ammonifying bacteria in non-shelf tillage by 1.5–5.7% compared to shelf tillage. The coefficient of mineralization – immobilization of nitrogen is significantly reduced by 3–13% with shallow tillage compared to differentiated.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author contributions

OT – writing a manuscript, analysis and interpretation of data;
MT, YM – acquisition of data, author of the idea, guided the research;
AB, DL, YS – analysis and interpretation of data and is the corresponding author, guided the research;
IK, YT – critical revision and approval of the final manuscript, guided the research.

References

Andreetta, A., Ciampalini, R., Moretti, P., Vingiani, S., Poggio, G., Matteucci, G., Tescari, F., Carnicelli, S., 2011. Forest humus forms as potential indicators of soil carbon storage in Mediterranean environments. – Biology and Fertility of Soils, 47:31–40. DOI: 10.1007/s00374-010-0499-z

Andreyuk, K.I., Iutinskaya, G.O., Antipchuk, A.F., Valagurova, O.V., Kozyrytska, V.E. 2001. Funktsionuvannya mikrobnykh tsenoziv gruntu v umovakh antropohennoho navantazhennya [Functioning of microbial coenoses of soil in the conditions of anthropogenic loading]. – Kyiv, Chary [Kyiv, Charms], 239 p. [In Ukrainian]

Balaev, A.D., Tonhka, O.L. 2013. Pochvozashchitnaya biologicheskaya sistema zemledeliya i vosproizvodstva plodorodiya pochv [Soil-protective biological system of agriculture and reproduction of soil fertility]. – Vestnik Natsional'nogo universiteta vodnogo khozyaystva i prirodopol'zovaniya [Bulletin of the National University of Water Management and Nature Management], 3(63):3–13. [In Russian]

Bastida, F., Zsolnay, A., Hernández, T., García, C. 2008. Past, present and future of soil quality indices: a biological perspective. – Geoderma, 147(3–4):159–171. DOI: 10.1016/j.geoderma.2008.08.007

Bending, G.D., Turner, M.K., Rayns, F., Marx, M.C., Wood, M. 2004. Microbial and biochemical soil quality indicators and their potential for differentiating areas under contrasting agricultural management regimes. – Soil Biology & Biochemistry, 36(11):1785–1792. DOI: 10.1016/j.soilbio.2004.04.035

Bilyavskaya, L.G., Sherstoboeva, O.V., Bilyavskaya, Y.V. 2010. Reaktsiya sortiv soyi na bakteryzatsiyu nasinnya za riznykh pohodnykh umov [Reaction of soybean varieties to bacterization of seeds under different weather conditions]. – Visnyk Poltavs′koyi derzhavnoyi ahrarnoyi akademiyi [Bulletin of the Poltava State Agrarian Academy], 4:47–49. [In Ukrainian]

Bittman, B., Forge, T.A., Kowalenko, C.G. 2005. Response of the bacterial and fungal biomass in a grassland soil to multi year applications of dairy manure slurry and fertilizer. – Soil Biology & Biochemistry, 37(4):613–623. DOI: 10.1016/j.soilbio.2004.07.038

Demyanyuk, O.S., Patyka, V.P., Sherstoboeva, O.V., Bunas, A.A. 2018a. Formuvannya struktury mikrobiotsenoziv gruntovykh ahroekosystem zalezhno vid trofichnykh i hidrotermichnykh faktoriv [Formation of the structure of microbiocenoses of soils agroecosystems depending on trophic and hydrothermic factors]. – Riznomanitnist′ biosystem [Biosystems diversity], 26(2):103–110. DOI: 10.15421/011816 [In Ukrainian]

Demyanyuk, O.S., Sherstoboeva, O.V., Tchaikovsky, V.V., Demidov, O.A. 2016. Spryamuvannya biolohichnykh protsesiv u grunti za riznykh system udobrennya ozymoyi pshenytsi ta pohodnykh umov [The direction of biological processes in the soil under different systems of winter wheat fertilization and weather conditions]. – Zbalansovane pryrodokorystuvannya [Balanced nature management], 2:146–151. [In Ukrainian]

Demyanyuk, O.S., Sherstoboeva, O.V., Tkach, E.D. 2018b. Funktsional′na struktura mikrobnykh uhrupovan′ hlybokoho chornozemu pid vplyvom hidrotermal′nykh ta trofichnykh faktoriv [Functional structure of microbial groups of deep chernozem under the influence of hydrothermal and trophic factors]. – Mikrobiolohichnyy zhurnal [Microbiological Journal], 80(6):94–108. DOI: 10.15407/microbiolj80.06.094 [In Ukrainian]

Demyanyuk, O.S., Sherstoboeva, O.V., Bunas, A.A., Dmitrenko, O.V. 2018c. Effects of different fertilizer systems and hydrothermal factors on microbial activity in the chernozem in Ukraine. – Biosystems Diversity, 26(4):309–315. DOI: 10.15421/011846

Emmerling, C, Udelhoven, T, Schröder, D. 2001. Response of soil microbial biomass and activity to agriculture deintensification over a 10 year period. – Soil Biology & Biochemistry, 33(15):2105–2114. DOI: 10.1016/S0038-0717(01)00143-2

Goberna, M., Sánchez, J., Pascual, J.A, Carcía, C. 2006. Surface and subsurface organic carbon, microbial biomass and activity in a forest soil sequence. – Soil Biology & Biochemistry, 38(8):2233–2243. DOI: 10.1016/j.soilbio.2006.02.003

Hopkins, D.W., Shiel, R.S. 1996. Size and activity of soil microbial communities in long-term experimental grassland plots treated with manure and inorganic fertilizers. – Biology and Fertility of Soils, 22:66–70. DOI: 10.1007/BF00384434

Hryhoriv, Y., Butenko, A., Nechyporenko, V., Lyshenko, M., Ustik, T., Zubko, V., Makarenko, N., Mushtai, V. 2021. Economic efficiency of *Camelina sativa* growing with nutrition optimization under conditions of Precarpathians of Ukraine. – Agraarteadus, 32(2):232–238. DOI: 10.15159/jas.21.33

Iutinskaya, G.O. 2006. Mikrobiolohiya gruntu [Soil microbiology]. – Kyiv, Aristey [Kyiv, Aristei], 284 p. [In Ukrainian]

Kaminskyi, V., Tkachenko, M., Malynovska, I., Kondratiuk, I., Pyndus, V., Asanishvili, N., Tkachenko, A. 2021. Preservation of acid Haplic Luvisols fertility and agrocenosis productivity increase under organic farming conditions. – Ukrainian Journal of Ecology, 11(3):328–335. DOI: 10.15421/2021_180

Kanchikerimath, M., Singh, D. 2001. Soil organic matter and biological properties after 26 years of maize–wheat– cowpea cropping as affected by manure and fertilization in a Cambisol in semiarid region of India. – Agriculture, Ecosystems & Environment, 86(2):155–162. DOI: 10.1016/S0167-8809(00)00280-2

Kaur, K., Kapoor, K.K., Gupta, A.P. 2005. Impact of organic manures with and without mineral fertilizers on soil chemical and biological properties under tropical conditions. – Journal of Plant Nutrition and Soil Science, 168(1):117–122. DOI: 10.1002/jpln. 200421442

Liang, Y.C, Si, J., Nikolic, M., Peng, Y., Chen, W., Jiang, Y. 2005. Organic manure stimulates biological activity and barley growth in soil subject to secondary salinization. – Soil Biology & Biochemistry, 37(6):1185–1195. DOI: 10.1016/j.soilbio.2004.11.017

Loboda, M.I., Voichuk, S.I., Biliavska, L.O. 2019. Korelyatsiyna zalezhnist′ biosyntezu antybiotychnykh spoluk ta inshykh biolohichno aktyvnykh rechovyn u gruntovykh streptomitsetakh [Correlation dependence between the antibiotic compounds biosynthesis and other biologically active substances in soil streptomycetes]. – Mikrobiolohichnyy zhurnal [Microbiological Journal], 81(5):36–47. DOI: 10.15407/microbiolj81.05.036 [In Ukrainian]

Manko, Yu, P., Tsyuk, O.A., Tsentulo, L.V., Shemetun, O. 2019. The methodology resource suggestion with environmental criteria for rationality agricultural systems estimation. – Ukrainian Journal of Ecology, 9(1):121–126.

Zvyagintsev, D.G. 1991. Metody mikrobiolohiyi ta biokhimiyi gruntu [Methods of soil microbiology and biochemistry]. – Moskva, MGU [Moscow, MSU], 303 p. [In Russia]

Nikiforenko, L.I. 1982. Rozpodil humusu v ornomu shari erodovanoho chornozemu zalezhno vid sposobiv obrobky [Distribution of humus in the arable layer of eroded chernozem depending on the methods of processing]. – Sil′s′ke hospodarstvo. Kyyiv, Urozhay [Agriculture. Kyiv, Urozhay], 55:76–81. [In Ukrainian]

Parkhomenko, M.M., Lychuk, A.I., Butenko, A.O., Karpenko, O.Yu., Rozhko, V.M., Tsyz, O.M., Chernega, T.O., Tymoshenko, O.P., Chmel, O.P. 2021. Nitrogen balance in short crop rotations under various systems for restoring sod-podzolic soil fertility. – Ukrainian Journal of Ecology, 11(2):72–76. DOI: 10.15421/2021_79

Patika, N.V., Kruglov, Y.V., Mazirov, M.A. 2010. Vyvchennya bioriznomanittya mikrobnoho kompleksu dernovo-pidzolystoho gruntu v umovakh bahatorichnoho sil′s′kohospodars′koho vykorystannya. Mizhvidomcha tema [Study of biodiversity of the microbial complex of sod-podzolic soil in the conditions of long-term agricultural use. Interdepartmental topic]. – Zhytomyr, 329–331. [In Ukrainian]

Patika, V.F. 2014. Biolohichnyy azot i nova stratehiya roslynnytstva v Ukrayini [Biological nitrogen and a new strategy for crop production in Ukraine]. – Naukovi zapysky Ternopil′s′koho natsional′noho pedahohichnoho universytetu. Seriya: Biolohiya [Scientific notes of Ternopil National Pedagogical University. Series: Biology], 3(60):10–15. [In Ukrainian]

Patika, V.P., Hnatyuk, T.G., Butsela, N.M., Kirilenko, L.V. 2015. Biolohichnyy azot v systemi sil′s′koho hospodarstva [Biological nitrogen in the system of agriculture]. – Sil′s′ke hospodarstvo [Agriculture], 2:12–20. [In Ukrainian]

Plaza, C., Hernandez, D., Garcia-Gil, J.C., Polo, A. 2004. Microbial activity in pig slurry-amended soils under semiarid conditions. – Soil Biology & Biochemistry, 36(10):1577–1585. DOI: 10.1016/j. soilbio.2004.07.017

Rieznik, S., Havva, D., Butenko, A., Novosad, K. 2021. Biological activity of chernozems typical of different farming practices. – Agraarteadus, 32(2):307–313. DOI: 10.15159/jas.21.34

Ros, M., Hernández, M.T., García, C. 2003. Soil microbial activity after restoration of a semiarid soil by organic amendments. – Soil Biology & Biochemistry, 35(3):463–469. DOI: 10.1016/S0038-0717(02)00298-5

Saiko, V.F. 2002. Sil′s′ke hospodarstvo v suchasnykh umovakh [Agriculture in modern conditions]. – Visnyk sil′s′kohospodars′koyi nauky [Bulletin of Agricultural Science], 5:5–10. [In Ukrainian]

Sarathchandra, S.U, Ghani, A., Yeates, G.W., Burch, G., Cox, N.R. 2001. Effect of nitrogen and phosphate fertilizers on microbial and nematode diversity in pasture soils. – Soil Biology & Biochemistry, 33(7–8):953–964. DOI: 10.1016/S0038-0717(00)00245-5

Sherstoboeva, O.V., Demyanyuk, O.S., Chabanyuk, Y.V. 2017. Biodiahnostyka ta biobezpeka gruntiv ahroekosystem [Biodiagnostics and biosafety of soils of agroecosystems]. – Ahroekolohichnyy zhurnal [Agroecological journal], 2:142–149. [In Ukrainian]

Tsyuk, O.A., Tanchyk, S.P., Kyrylyuk, V.I., Shevchenko, T.V. 2018. Biolohichna aktyvnist′ gruntu u svynomatok ozymoyi pshenytsi zalezhno vid osnovnoyi obrobky gruntu v poslidovnosti [Biological activity of the soil in sows of winter wheats depending on the main soil treatment in sequence]. – Ukrayins′kyy ekolohichnyy zhurnal [Ukrainian Journal of Ecology], 8(3):37–40. [In Ukrainian]

Tu, C., Rustaino, J.B., Hu, S. 2006. Soil microbial biomass and activity in organic tomato farming systems: effects of organic inputs and straw mulching. – Soil Biology & Biochemistry, 38(2):247–255. DOI: 10.1016/j.soilbio.2005.05.002

Volkogon V., Dimova S., Volkogon K. 2010a. Vplyv mikrobnykh dobryv na zasvoyennya pozhyvnykh rechovyn kul′turnymy roslynamy [Influence of microbial fertilizers on the assimilation of nutrients by cultivated plants]. – Visnyk sil′s′kohospodars′koyi nauky [Bulletin of Agricultural Science], 5:25–28. [In Ukrainian]

Volkogon, V.V., Nadkernicna, O.V., Tokmakova, L.M. 2010b. Eksperymental′na mikrobiolohiya gruntu [Experimental soil microbiology]. – Kyiv, Agrarna nauka [Kyiv, Agrarian Science], 464 p. [In Ukrainian]