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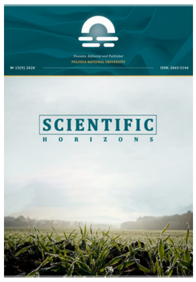

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Microbial activity of dark-chestnut soil in winter wheat crops depending on fertiliser application

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Abstract. Preventing soil degradation is an important task of modern agrarian science. Preservation and increase in beneficial soil microflora are a precondition for satisfactory ecological functioning of soil and its fertility. The purpose of this study was to investigate the dynamics of beneficial soil microflora in winter wheat crops under the impact of mineral fertilisers and *Agrobacterium radiobacter* on the lands of the south of Ukraine. The study was conducted in threefold replication in the conditions of the Kherson region in 2016-2020 in the experimental fields of the Institute of Climate-Smart Agriculture of the National Academy of Agrarian Sciences of Ukraine. The study used a systematic design, and the following factors were investigated: no fertiliser and *Agrobacterium radiobacter*; $N_{120}P_{90}$; $N_{90}P_{60}$ + *Agrobacterium radiobacter*; $N_{120}P_{90}$ + *Agrobacterium radiobacter*. The study on the microflora composition in the soil layer at 0-30 cm was carried out in the main stages of winter wheat growth and development through the inoculation of nutritious environment. Statistical analysis was performed using the methods of analysis of variance, correlation, and regression analysis. Dynamic changes in the soil biota composition under the influence of the studied factor were established. The slightest response to mineral fertilisers and bacterial preparation application was in ammonifying bacteria, while the strongest response was in cellulose-degrading microorganisms. The winter wheat harvesting revealed a decrease in the number of ammonifying bacteria in the soil, while the number of nitrifying and cellulose-degrading microflora increased significantly. Regression models for the prediction of the number of nitrifying bacteria and cellulose-degrading microorganisms, developed based on experimental data, have great accuracy (the error is 3.78% and 7.79%), and allow determining the adverse effect of phosphorus fertiliser on the microflora of dark-chestnut soil. The study has no analogues in Ukraine and expands theoretical knowledge about the influence of mineral fertilisers and bacterial preparation, containing *Agrobacterium radiobacter,* on the composition of beneficial microflora of the dark-chestnut soil

Keywords: ammonifying bacteria; bioaugmentation; nitrifying bacteria; cellulose-degrading microorganisms; mathematical modelling

INTRODUCTION

Soil degradation is less discussed and popularised than global warming, but not a less hazardous challenge standing before the humankind in the 21st century. Deterioration of soil quality and poor soil health in some regions reach the peak point and immediate intervention is required to preserve this non-renewable resource for crop production. If no steps are taken, the degraded soils will be abandoned and deserted (Panagos *et al.*, 2018). Assuming that soil is not only an irreplaceable natural resource for food production, but also an important link of the general ecological chain of the biosphere, soil and land degradation is a threat for global food security, biodiversity preservation, and general well-being of the Earth. Current irrational intensification of agricultural land use practices resulted in extreme deterioration of soil quality on the global scale (Kopittke *et al.,* 2019).

It is assumed that the Mediterranean is the most susceptible region in Europe in the context of deterioration of soil quality and desertification. H. Shao *et al.* (2019) proved that some soils of the Mediterranean basin are in critical state, and soon they will be unable to provide not only crop production, but even elementary ecosystem services. According to C.S. Ferreira *et al.* (2022), soils are subjected to degradation on three main levels: biological (loos of soil microbiome diversity, shifts to the prevalence of harmful flora over the beneficial); chemical (decrease in soil organic matter content, contamination with chemical wastes, salinisation); physical (sealing, over compaction, erosion).

A. Drobitko *et al.* (2023) noted that even though Ukraine does not belong to the Mediterranean region of Europe, it is well-known that in recent decades soil degradation processes take place on the entire area of the country. Apart from the negative transformations mentioned above, which are common for the Mediterranean and Ukrainian soils, the latter are subjected to other negative impacts. According to D. Rawtani *et al.* (2022), in the last two years, soil health deterioration has extremely accelerated, especially in the south and in the east of Ukraine, because of military activities, which lead to destruction of the upper fertile soil layers, soil pollution with heavy metals, radioactive trace elements, toxic chemicals and harmful bacteria, diminishment of the number of biologically active beneficial microorganisms, flooding, covering with silt, over-compaction, etc. Combined with irrational agricultural practices of land-use, inherited from the Soviet Union era, extremely high share of arable lands in the structure of croplands, neglection of organic fertilisers application, introduction of high-intense, soil-exhausting short crop rotations with row crops (such as maize, soybeans, sunflower, grain sorghum) and complete replacement of perennial herbs from crop rotations, irrational irrigation and soil tillage practices at the background of adverse effects of natural phenomena, driven by climate change, technogenic impacts connected with current military activities and absence of reliable scientific information support in the sphere of land use and soil regulation are absolutely destructive for the soils of the south and east of the country (Malashevskyi *et al.*, 2020).

P. Pereira *et al.* (2022) note that general land surface topography has been changing since the beginning of the war due to impacts of shelling and military construction, especially trenches and fortification building. Researchers P.V. Lykhovyd and Ye.V. Kozlenko (2018) noted low irrigation water quality (e.g., Ingulets irrigation system, which became the only body to supply irrigation water to the fields of the south after the destruction of Kakhovka dam) and poor land reclamation practices, malfunction of major irrigation and drainage systems, leading to secondary alkalisation and additional structural damage to the soil texture, and the situation starts to look horrible. In this regard, studies on soil health preservation and improvement are of great relevance and importance for current agriculture.

Soil health improvement could be achieved in different ways. As mentioned above, there are three main levels of soil degradation, and there are three corresponding levels of soil quality improvement. One of the crucial but less studied ones is biological level. Soil microorganisms play crucial role in ecosystem services, maintaining soil fertility, balance of organic and mineral matter, and are of great importance for sustainable crop production and ecological stability. This is especially relevant to the arid environments, suffering from rapid climate change, such as of the south of Ukraine, where healthy soil biota composition contributes to ecological sustainability and integrity of total ecosystems (Mishra & Singh, 2020). Therefore, it is necessary to learn about practices that help support a healthy soil biota. P.V. Lykhovyd and S.O. Lavrenko (2017), and B. Futa *et al.* (2021) note that fertilisation practices require robust investigation, because fertiliser application has been shown to lead to significant changes in soil biological and enzymatic activity, measured in different ways.

According to A. Sumbul *et al.* (2020), apart from mineral fertilisers, bacterial preparations, applied during the cultivation of various crops or for the purposes of biological remediation, also have some impact on soil health. Considering current scientific evidence that bioaugmentation in the combination with phytoremediation approach could be extremely beneficial for soil fertility improvement, it is necessary to investigate this question in greater detail for a certain biological agent and soil type (Zanganeh *et al.,* 2022).

The purpose of this study was to reveal the impact of mineral fertilisers and non-symbiotic nitrogen-fixing bacteria application in winter wheat crops on the favourable biota composition of dark-chestnut soil, namely, ammonifying, nitrifying bacteria, and cellulose-degrading microorganisms; to substantiate beneficial and harmful effects of mineral fertilisers and bioaugmentation on the health of the soil.

MATERIALS AND METHODS

Field experiments devoted to the investigation of the effects of mineral fertilisers and bioaugmentation agents on the biota composition of dark chestnut soil were conducted during 2016-2020 at the Institute of Climate-Smart Agriculture of the National Academy of Agrarian Sciences of Ukraine (NAAS). The experimental field was located in Bilozerka district of Kherson region, the south of Ukraine (geographical coordinates: 46°44′33″N 32°42′28″E). In climatological relation, the area of the trials belongs to the dry steppe zone of Ukraine, or BSk (cold semi-arid climate zone) according to M.C. Peel *et al.* (2007). The soil of the experimental field was represented by dark-chestnut middle-loamy soil with humus content in the arable layer averaging 2.2%. The field capacity of the 0-100 cm layer is 22.4%, wilting point is 9.5%. Groundwater is beyond 10 m. The experiment was conducted using the systematic design of the study in threefold replication. The area of the experimental plot of the first grade was 500 m^2, while accountable area was 100 m^2. The area of the second-grade plot was 50 m^2. The scheme of the experiment is presented in the Figure 1.

Figure 1*. The scheme of the experiment, conducted at the field in Bilozerka district of Kherson region during 2016-2020*

Note*: the numbers in the Figure 1 correspond to the variants 1, 2, 3, 4 of the study; St. – standard, control variant of the study*

Source: *created based on the authors' own research*

Winter wheat was sown as the basic crop in the study. Cultivation technology used in the experiment was common for the conditions of the south of Ukraine, except from the factors under study (Domaratskiy *et al.*, 2019). The studied factors, namely fertilisers and bioaugmentation agent application, had the following gradations: variant 1 (St.) – no fertiliser and bioaugmentation agent; variant 2 – $N_{120}P_{90}$; variant 3 – $N_{90}P_{60}$ + non-symbiotic nitrogen-fixing bacteria (NSNFB); variant 4 – $N_{120}P_{90}$ + NSNFB. The NSNFB preparation was represented by Diazophit, which contains 4-6 billion of

Agrobacterium radiobacter strain per 1 g/ml. This bioaugmentation preparation has been developed specifically for wheat, barley, and rice crops (Khomenko *et al.*, 2010).

The number of ammonifying, nitrifying bacteria, and cellulose-degrading microorganisms in the soil was determined in the certified analytical studies laboratory of the Institute of Climate-Smart Agriculture of NAAS. The study was performed for the soil layer at 0-30 cm in three main stages of winter wheat development: start of the growing season (BBCH 10-13), stem elongation (BBCH 31-37), and full ripeness of grain (BBCH 89-91). Soil samples were collected using a special soil auger. The soil suspension was sown in different nutritious environment. To determine the number of ammonifying bacteria, meat-peptone agar (MPA) was used, and to determine the number of nitrifying bacteria, watery agar with ammonium-magnesium salt was used. After inoculation with the nutritious environment, the incubation period (14 days) began, when the temperature was maintained at +28°C. After the incubation period, the number of colonies was accounted for. The number of the soil biota for each species group is represented in the colony-forming units (CFUs) per 1 g of the absolutely dry soil. The moisture content in the soil was calculated using the gravimetric method. All laboratory studies were conducted in threefold replication. Statistical data processing was performed using Microsoft Excel 365 spreadsheets (pairwise linear correlation analysis by Pearson), AgroStat (one-way analysis of variance), BioStat v.7 (multiple linear regression analysis) statistical packages. All calculations were performed at $p<0.05$ using common mathematical procedure (Scheffe, 1999; Sharma, 2005).

RESULTS AND DISCUSSION

As a result of the study, the major regulations on microbiota transformation in dark-chestnut soil were established under the influence of mineral fertilisers and the biological preparation Diazophit (Table 1). First of all, it should be certified that the variants of $N_{90}P_{60}$ + NSNFB and $N_{120}P_{90}$ + NSNFB did not differ significantly at the stage of stem elongation (BBCH 31-37) of winter wheat in terms of the number of ammonifying and cellulose-degrading microflora. These variants were also similar in the latest stage of crop growth in terms of the presence of ammonifying bacteria in the soil. Furthermore, there was no statistically significant difference between the variants without fertilisers and fertilised with $N_{120}P_{90}$ in terms of all microflora species studied in the BBCH 89-91 stage. However, generally, the number of all the studied soil microbiota species was significantly higher in the variants with the application of Diazophit as a bioaugmentation agent. Therefore, it was proved that application of *Agrobacterium radiobacter* is beneficial for preservation of favourable microflora in the dark-chestnut soil under the cultivation of winter wheat. This conclusion is in line with the statements that can be found in the scientific reports of studies on this subject (Kovalenko *et al.*, 2020).

Table 1. *Microbial composition of the dark-chestnut soil in the winter wheat crops depending on mineral fertilisers and the bacterial preparation application (average for 2016-2020)*

Variant	CFU per 1 g of the absolutely-dry soil		
	Ammonifying bacteria, billion	Nitrifying bacteria, billion	Cellulose-degrading microorganisms, thousand
BBCH 10-13			
No fertilisers	28.50a	8.76a	3.36a
$N_{120}P_{90}$	29.37b	9.10b	3.91b
$N_{90}P_{60}$ + NSNFB	35.63c	10.15c	4.30c
$N_{120}P_{90}$ + NSNFB	33.08d	9.89d	4.28c
BBCH 31-37			
No fertilisers	18.97a	8.93a	3.53a
$N_{120}P_{90}$	20.25b	9.40b	3.93b
$N_{90}P_{60}$ + NSNFB	22.86c	10.89c	4.18c
$N_{120}P_{90}$ + NSNFB	21.58c	10.61d	4.20c
BBCH 89-91			
No fertilisers	24.62a	10.49a	3.98a
$N_{120}P_{90}$	25.62a	10.56a	4.00a
$N_{90}P_{60}$ + NSNFB	28.00b	13.12b	4.68b
$N_{120}P_{90}$ + NSNFB	27.22b	12.14c	4.57c

Note: *different letters in the labels of each value certify about statistically significant difference between the variants at $p<0.05$ according to the ANOVA test results*

Source: *compiled by the authors of this study based on the authors' own research*

Notably, the number of nitrifying bacteria and cellulose-degrading microorganisms gradually increased from the very beginning to the cessation of winter wheat growth in all the variants of the experiment. However, the dynamics for ammonifying bacteria was different: their numbers significantly decreased to the stage of stem elongation (BBCH 31-37) in winter wheat, but then slightly increased before the crop's growth cessation (BBCH 89-91). Despite the increase in the late stages of winter wheat development, the number of ammonifying bacteria had negative balance by the growing season (Table 2).

Table 2. *The dynamics of microbial composition of the dark-chestnut soil in the winter wheat crops depending on mineral fertilisers and the bacterial preparation application (average for 2016-2020; the dynamics is presented relatively to the initial numbers of the bacteria)*

Variant	CFU per 1 g of the absolutely-dry soil		
	Ammonifying bacteria, billion	**Nitrifying bacteria, billion**	**Cellulose-degrading microorganisms, thousand**
	BBCH 31-37		
No fertilisers	-9.53	0.17	0.17
$N_{120}P_{90}$	-9.12	0.30	0.02
$N_{90}P_{60}$ + NSNFB	-12.77	0.74	-0.12
$N_{120}P_{90}$ + NSNFB	-11.50	0.72	-0.08
	BBCH 89-91		
No fertilisers	-3.88	1.73	0.62
$N_{120}P_{90}$	-3.75	1.46	0.09
$N_{90}P_{60}$ + NSNFB	-7.63	2.97	0.38
$N_{120}P_{90}$ + NSNFB	-5.86	2.25	0.29

Source: *compiled by the authors of this study based on the authors' own research*

The highest negative balance was established for $N_{90}P_{60}$ + NSNFB, while the variant with the application of mineral fertilisers at the $N_{120}P_{90}$ rates resulted in the best preservation of the community of ammonifying bacteria in the soil. The best positive balance of nitrifying bacteria was achieved by $N_{90}P_{60}$ + NSNFB, while the best survival and increase rates in cellulose degrading microorganisms were fixed in the variant without applied fertilisers. These results demonstrate that different microflora react differently to the application of mineral fertilisers and bioaugmentation. Notably, established regulations can be unique for the dark-chestnut middle-loamy soil of the steppe zone, as it was shown that there are different patterns of seasonal dynamics and the presence of beneficial microflora under different environmental conditions (Ishaq *et al.*, 2020). Furthermore, as suggested by H. Wang *et al.* (2022), elements of cultivation technology, especially tillage, could also be involved in the regulation of the soil microbiota. Therefore, these specific features should be also considered in the interpretation of the results. The correlation-regression analysis allowed establishing the nature and strength of the relationship between the microbial composition of the dark-chestnut soil in the winter wheat crops and the application of mineral fertilisers (Table 3).

Table 3. *Pairwise relationship between the microbial composition of the dark-chestnut soil in the winter wheat crops and mineral fertilisers and the bacterial preparation application (average for 2016-2020)*

Bacterial community	Correlation coefficient			Determination coefficient		
	Nitrogen fertilisers, kg ha^{-1}	**Phosphorus fertilisers, kg ha^{-1}**	**NSNFB**	**Nitrogen fertilisers, kg ha^{-1}**	**Phosphorus fertilisers, kg ha^{-1}**	**NSNFB**
Ammonifying	0.21	0.18	0.36	0.04	0.03	0.13
Nitrifying	0.33	0.29	0.64	0.11	0.09	0.14
Cellulose-degrading	0.63	0.59	0.80	0.39	0.34	0.64

Source: *compiled by the authors of this study based on the authors' own research*

As a result, it was found that there is almost no connection between the application of mineral fertilisers and the number of ammonifying and nitrifying bacteria, while the relationship between the rates of nitrogen and phosphorus application is moderately correlated with the presence of cellulose-degrading microorganisms in the soil. Therewith, it was established that the application of the NSNFB preparation

Diazophit was moderately related to the number of nitrifying bacteria and strongly related to the number of cellulose-degrading microorganisms in the soil. Therefore, ammonifying bacteria were the only one species that were not affected by the factor under study. The results of multiple regression analysis revealed a weak dependence of the presence of ammonifying bacteria on the complex of fertilisers used, while nitrifying bacteria and cellulose-degrading microorganisms demonstrated moderate-to-strong dependence on the complex effects of the factor under study (Table 4).

Table 4. *Multiple relationship between the microbial composition of the dark-chestnut soil in the winter wheat crops and mineral fertilisers and the bacterial preparation application (average for 2016-2020)*

Bacterial community	Correlation coefficient	Determination coefficient
Ammonifying	0.39	0.15
Nitrifying	0.66	0.44
Cellulose-degrading	0.86	0.74

Source: *compiled by the authors of this study based on the authors' own research*

Multiple regression models for the prediction of soil microbiota composition depending on the fertiliser's application and use of Diazophit were developed for the nitrifying and cellulose-degrading microflora (Tables 5 and 6).

Table 5. *Regression statistics and the model for the prediction of nitrifying bacteria numbers in the dark-chestnut soil based on the fertilisation rates and application of the bacterial preparation*

Statistical parameter	Value
Adjusted coefficient of determination	0.23
Predicted coefficient of determination	0.26
Mean absolute percentage error	7.79%
Mean square error	1.30 CFU
Equation	$9.3933E + 1.1933NSNFB - 7.7333 \times 10^{-2}P + 6.0444 \times 10^{-2}N$

Note: *N – the dose of Nitrogen fertilisers applied, kg ha*$^{-1}$*; P – the dose of Phosphorus fertilisers applied, kg ha*$^{-1}$*; NSNFB – application (enter "1") or no application (enter "0") of the bacterial preparation Diazophit*
Source: *compiled by the authors of this study based on the authors' own research*

Table 6. *Regression statistics and the model for the prediction of cellulose-degrading microorganisms' numbers in the dark-chestnut soil based on the fertilisation rates and application of the bacterial preparation*

Statistical parameter	Value
Adjusted coefficient of determination	0.64
Predicted coefficient of determination	0.41
Mean absolute percentage error	3.78%
Mean square error	0.05 CFU
Equation	$3.6233 + 0.4033NSNFB - 1.5667 \times 10^{-2}P + 1.4444 \times 10^{-2}N$

Note: *N – the dose of Nitrogen fertilisers applied, kg ha*$^{-1}$*; P – the dose of Phosphorus fertilisers applied, kg ha*$^{-1}$*; NSNFB – application (enter "1") or no application (enter "0") of the bacterial preparation Diazophit*
Source: *compiled by the authors of this study based on the authors' own research*

The proposed models are the first to provide a mathematical description of the influence of mineral fertilisers and the effects of *Agrobacterium radiobacter* on the beneficial microflora of dark-chestnut soil. According to the regression model coefficients, phosphorus fertilisers have negative impact on both species, while nitrogen fertilisers are favourable for their development.

Other scientists have also investigated this subject, but from other perspectives. However, main conclusions are not contradictory. Thus, M. Sintia *et al.* (2021) have also proven a strong effect of nitrogen fertilisation on nitrifying microbes and net nitrification rates in soils under cereal and leguminous crops. As for cellulose-degrading soil microflora, H. Tang *et al.* (2021) established positive effects of organic manure and crop residue application on the studied group of soil biota. Authors also claimed that the cellulolytic microbial community studied in soils was significantly increased with the long-term application of crop residue (so-called green manure) and the organic manure condition comparing with pure mineral fertilisation practices. However,

Q. Ma *et al.* (2020) do not support this statement and claim that farmyard manure application has no effect on soil microbial community structure. As for the action of bacterial preparations, J. Wang *et al.* (2020) found that some bacterial species, when added into soil community, can enhance cellulose degradation activity in soils under simultaneous increase in the volume of available nitrogen, phosphorus, and potassium, thereby improving soil fertility and crop production.

A. Iminov *et al.* (2020) claimed that application of mineral fertilisers together with nitragin increased the number of ammonifiers, oligonitrophils, and micromycetes in soybean crops. Y. Chen *et al.* (2018) found that mineral fertilisation with nitrogen, phosphorus, and potassium in appropriate proportions is the best approach to improve soil quality and soil bacterial community in non-calcareous fluro-aquic soils of the North China Plain. Z. Liu *et al.* (2021) reported the highest bacterial enzymes activity in the soils of Shaping, Hequ, China, when complex approach to soil fertilisation was implemented, viz., application of appropriate doses of organic manure and mineral fertilisers.

However, meta-analysis on soil microbiota and its relation to fertilisation systems found that manure application is beneficial, while mineral nitrogen, phosphorus, and potassium fertilisers in some soils led to significant loss of microbial biomass (Ren *et al.*, 2019). Y. Kong *et al.* (2019) also support the statement that long-term chemical fertilisation significantly decreases soil nitrifying activity. Finally, in case of different crop rotations and fertilisation practices different changes in soil bacterial diversity and functioning will be observed, as reported by Z. Tong *et al.* (2023). The strongest differences are observed between cereal and leguminous crops, as the latter are the substrate for symbiotic nitrogen-fixing bacteria colonisation, leading to significant shifts in soil microbiome (Zhang *et al.*, 2019).

As for *Agrobacterium radiobacter* application, I. El Attar *et al.* (2022) found beneficial effects of these bacteria on soil fertility and crop production, suggesting the possibility of partial replacement of nitrogen mineral fertilisers with this bacterial agent. L. Tokmakova *et al.* (2019) found that *Agrobacterium radiobacter* improves plants nutrition with phosphorus, providing for the improvement of maize yields. However, caution should be taken when applying *Agrobacterium radiobacter* preparations because these bacteria are pathogens for some agricultural species, e.g., pistachio seedlings (Basavand *et al.*, 2022), while some other crops should be provided with additional protection, especially potato (Borodaj & Parfeniuk, 2019).

Therefore, considering that the presented study is in good agreement with the internationally conducted investigations, even those carried out on other types of soils and in other environmental and agrotechnological conditions, it can be assumed that the mathematical models developed for the prediction of soil microbiome composition depending on the nitrogen, phosphorus, and *Agrobacterium radiobacter* application rates could be applied for scientific purposes not only for the dark-chestnut soils of the south of Ukraine, but for other soils and climate zones as well.

CONCLUSIONS

The findings of this study revealed that the application of *Agrobacterium radiobacter* and mineral fertilisers significantly affects the number of beneficial soil microbiota. A stronger effect was attributed to nitrifying bacteria, while ammonifying bacteria almost did not experience any positive or adverse effect from the application of the substances under study. The strongest effects of the studied factor were observed for the cellulose-degrading microorganisms, which reacted the most on the application of *Agrobacterium radiobacter* – correlation coefficient was 0.80. It was found that the number of ammonifying bacteria in the dark-chestnut soil decreased over the growing season of winter wheat (by 3.75-12.77 CFU/g of the absolutely-dry soil depending on the variant of the study), while the numbers of nitrifying bacteria increased up to 1.46-2.97 CFU/g of the absolutely-dry soil by the end of the study. Statistical analysis allowed multiple regression models to be developed for the prediction of the number of nitrifying bacteria and cellulose-degrading microorganisms in the dark-chestnut soil. The models provide high predictive accuracy (MAPE values are 3.78% and 7.79% for cellulose-degrading and nitrifying microbiota, respectively; correlation coefficients of the models are 0.86 and 0.66 for cellulose-degrading and nitrifying microbiota, respectively) and could be used in scientific purposes for simulation studies of the microbial community of the dark-chestnut soils of the South of Ukraine. It was additionally established that phosphorus application plays negative role in the formation of nitrifying and cellulose-degrading microflora, namely, every kg ha^{-1} of phosphorus mineral fertiliser decreases the number of nitrifying bacteria by 0.077 CFU/g of the absolutely-dry soil, and the number of cellulose-degrading bacteria decreases by 0.016 CFU/g of the absolutely-dry soil, respectively.

More research should be conducted to improve the knowledge on this topic. First of all, additional agrotechnological factors (e.g., tillage, irrigation ways) should be included, as well as it would be beneficial to include other types of crops in the future studies. Furthermore, other soil types (chernozems, greyzems, etc.) should also be investigated in terms of the impacts of agrotechnology on their microbial composition.

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CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

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Мікробна активність темно-каштанового ґрунту в посівах озимої пшениці залежно від застосування добрив

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Анотація. Попередження деградації ґрунтів є важливим завданням сучасної аграрної науки. Збереження та примноження корисної ґрунтової мікрофлори є запорукою забезпечення екологічної функції ґрунтів і їх родючості. Метою даної роботи є вивчення динаміки корисної ґрунтової мікрофлори на посівах пшениці озимої під впливом мінеральних добрив та *Agrobacterium radiobacter* на землях півдня України. Дослідження виконували в трьох разовій повторності в умовах Херсонської області у період 2016-2020 рр. на експериментальних полях Інституту кліматично орієнтованого сільського господарства Національної академії аграрних наук України. Розташування варіантів досліду – систематичне, вивчали наступні фактори: без добрив і *Agrobacterium radiobacter*; $N_{120}P_{90}$; $N_{90}P_{60}$ + *Agrobacterium radiobacter*; $N_{120}P_{90}$ + *Agrobacterium radiobacter*. Вивчення складу мікрофлори у шарі ґрунту 0-30 см виконували у основні фази росту і розвитку пшениці озимої в лабораторних умовах шляхом висівання суспензії на живильні середовища. Статистичний аналіз даних виконували методами дисперсійного, кореляційного та регресійного аналізу. Було встановлено динамічні зміни у складі ґрунтової біоти під впливом досліджуваного фактора. Мінімальну відповідь на внесення мінеральних добрив і бактеріального препарату мали амоніфікуючі бактерії, максимальну – целюлозо-розкладаючі мікроорганізми. Встановлено зменшення чисельності амоніфікуючих бактерій у ґрунті до періоду збирання пшениці озимої, у той час як чисельність нітрифікуючих бактерій і целюлозо-розкладаючої мікрофлори істотно зростала. Регресійні моделі прогнозу чисельності нітрифікуючих бактерій і целюлозо-розкладаючої мікрофлори, розроблені на основі експериментальних даних, мають високу точність (похибка склала 3,78 і 7,79 %), і дозволили встановити негативний вплив фосфорних добрив на мікрофлору темно-каштанового ґрунту. Дослідження не має аналогів в Україні та поглиблює теоретичні знанні щодо впливу мінеральних добрив і бактеріального препарату на основі *Agrobacterium radiobacter* на склад корисної мікрофлори темно-каштанового ґрунту

Ключові слова: амоніфікуючі бактерії; біологічне поліпшення; нітрифікуючі бактерії; целюлозо-розкладаючі бактерії; математичне моделювання