



Microbiological activity of soil and its impact on maize productivity when applying biologics

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Abstract. The purpose of this study was to assess the state of microbial coenosis and the activity of microbiological processes in the soil, their impact on the agrochemical parameters of typical chernozem, the assimilation surface of maize leaves and its seed productivity when applying biologics. In the study, a field method was used to investigate the interaction of research objects with natural factors, a laboratory method for determining microbiological and agrochemical indicators and photosynthetic activity, and a mathematical and statistical method for processing experimental data. It was established that with the introduction of biologics Groundfix and Azotohelp in favourable weather conditions in 2023 and arid 2024, the number of microorganisms of the vast majority of agronomically valuable groups increased compared to the control, the intensity of transformation of organic matter in the soil, and the intensity of mineralisation processes and potential denitrification activity decreased, and there was a decrease in the deficit of nutrients that were easily accessible to the microbiota. A high inverse relationship was

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established between the content of mineral nitrogen in the soil and the intensity of mineralisation processes in it ($r = -0.78$) and denitrification activity ($r = -0.77$). However, there was a direct effect of leaf assimilation surface and leaf dry matter on yield ($r = 0.71$ and 0.65 , respectively). The efficiency of maize cultivation increased with the introduction of biologics Groundfix and Azotohelp by 6% and 5%, respectively. It was determined that the use of biologics Groundfix and Azotohelp in a row during sowing contributed to increasing the biogenicity of the soil and optimising microbiological processes in it, increasing the availability of nutrients and their digestibility, while contributing to plant growth and intensification of photosynthetic activity. Due to positive changes from the use of biologics Groundfix and Azotohelp, the yield of maize to the control version increases by 0.50 and 0.45 t/ha, respectively. These results can be used to optimise intensive maize cultivation technology, which will help to improve the state of microbial coenosis of the soil, plant nutrition, and increase maize yield

Keywords: microbial preparations; typical chernozem; physiological and taxonomic groups of microorganisms; denitrification activity; agrochemical indicators; yield

INTRODUCTION

In the conditions of intensive agriculture, the problem of preserving and restoring soil fertility becomes particularly important. Excessive use of mineral fertilisers, pesticides, and other agrochemicals leads to soil degradation, a decrease in their biological activity and a violation of the natural balance of agroecosystems. In this regard, there is a growing interest in the use of biological methods to increase soil fertility, in particular, the use of biologics based on beneficial microorganisms. They not only help to improve the microbiological condition of the soil, but also provide plants with nutrients, increase their resistance to stress factors and contribute to the development of a high-quality crop. Therefore, the study of the influence of the soil microbial complex on the agrochemical properties of the soil and the productivity of agricultural crops is extremely relevant for both science and practice.

Such researchers as O.M. Trus *et al.* (2021) emphasised the importance of soil microorganisms in ensuring the biological activity of the soil, which was the basis for its fertility and plant nutrition. L.M. Tokmakova *et al.* (2021) noted that microbiological processes that occur with the participation of microorganisms that destroy organic matter contribute to the effective decomposition of plant residues, improve the microbiological state of the soil, and improve the quality and yield of agricultural crops. R. Walker *et al.* (2020) reviewed current approaches and prospects for the use of microorganisms in agriculture, in particular, in improving plant growth, increasing yields and resistance to stress factors. The researchers emphasised the importance of investigating the metabolic

interactions between plants and the microbiota, and the potential of biotechnological solutions for sustainable agriculture. However, N.G. Iyanyi (2020), Yu. Borko *et al.* (2022) proved that it was the direction of soil microbiological processes that determined the level of supply of plants with the necessary nutrients, which lead to the development of crop productivity. Microorganisms, being in close interaction with all elements of the biocenosis, form a complex system: “soil-plant-microorganisms”, the functioning of which causes the destruction of organic matter, the cycle of biogenic elements, and the preservation of fertility. E. Menendez *et al.* (2020) in their study emphasised that the use of consortia of probiotic bacteria in agriculture can have a significant positive effect, because the interaction of rhizobial and non-rhizobial bacteria contributes to the improvement of the growth and development of cultivated plants. V.V. Bolokhovskiy *et al.* (2024a) emphasised that the use of biologics in sunflower cultivation technologies contributed to the optimisation of plant mineral nutrition. The researchers pointed out that the use of complexes of beneficial microorganisms activated the processes of fixation of atmospheric nitrogen, dissolution of hard-to-reach forms of phosphorus, and also increased the resistance of plants to biotic and abiotic stresses, preserving the natural biocenosis of the soil. According to Yu.P. Borko *et al.* (2021), the physiological effect of using biologics was to improve the processes of plant life, namely, to better absorb nutrients, enhance the processes of photosynthesis, which, in turn, contributed to an increase in yield and allowed the crop to maximise its



potential. Scientific sources noted that the use of biologics, which include effective microorganisms, is a necessary element in the development of stable, environmentally balanced, and productive agroecosystems in contemporary agricultural production (Sherstoboeva *et al.*, 2020; Chen *et al.*, 2021; Wei *et al.*, 2024).

However, the variety of microbial preparations proposed for use in the agricultural sector encourages the search for scientific substantiations for the relationship between the course of microbiological processes in the soil and the development of agricultural crops. The purpose of the study was to establish the relationship between the activity of microbiological processes, agrochemical indicators of typical chernozem, the development of the photosynthetic apparatus of maize plants and its productivity when applying biologics.

MATERIALS AND METHODS

The research was conducted during 2023-2024 in the production conditions of Druzhba Nova JLLC (Kernel agricultural holding). In 2023, the research programme was implemented on experimental plots of agricultural land located in the administrative divisions of the Lubny district, Poltava Oblast (Pochaivka village), and in 2024 – Pryluky district of Chernihiv Oblast (Varva village), which were used by the Kernel agricultural holding. The soils of the experimental plots were represented by typical low-humus medium-loamy chernozem on loessial rocks. The technology of growing hybrid maize DKC 3972 on experimental plots in both locations is generally accepted for the Kernel agricultural holding in the Forest-Steppe zone, namely: the predecessor was maize for grain, the fertilisation background was $N_{110}P_{50}K_{50}$, the maize seeding rate was 80 thous. U/ha.

The research was conducted according to generally accepted methodological approaches in the field of agronomy (Rozhkov *et al.*, 2016). Experimental area – 7,168 m², the area of the sown plot in one replication of each variant is 448 m², the area where the harvest was recorded (without side and end protection strips) is 311 m², repetition – fourfold, placement of experimental sites was systematic. Crop accounting was carried out by continuous threshing of grain from each site, followed by recalculation to 14% of the basic humidity. The obtained findings were processed by variance,

correlation, and regression methods of analysis using special application suite – Excel-16.0 (Yeshchenko, 2005).

The study considered options for applying soil biologics in rows during maize sowing according to the scheme:

1. Control (without introduction of LCFs and biologics);
2. LCF 5-20-5. 25 kg/ha;
3. Groundfix, 1 l/ha;
4. Azotohelp, 1 l/ha.

Liquid complex fertilisers (LCFs) and biologics were applied at a working solution consumption rate of 50 l/ha during maize sowing with a Great Plains 8070 seed drill equipped with applicators for applying liquid fertilisers in rows. Technologies for growing maize, in addition to the factors under study, were typical for the Kernel agricultural holding in the Forest-Steppe zone. For control was the option on which liquid complex fertilisers and biologics were not added in rows. LCF 5-20-5 – liquid nitrogen-phosphorus-potassium fertiliser, the mass fraction of nitrogen (N) – 5%, phosphorus (P) – 20%, and potassium (K) – 5%. It was applied as a starting fertiliser to the soil during sowing in a row at a rate of 25-75 kg/ha. The maximum safe application rate for seeds and seedlings depended on the crop, row spacing, granulometric composition, soil temperature and humidity, its cation exchange capacity and organic matter content, applicator design and some other factors.

Groundfix phosphorus-potassium mobiliser is a soil microbiological fertiliser. The main action of the biological product is to improve the phosphorus-potassium nutrition of plants by converting phosphates to a soluble form, and increasing the mobility and availability of silicon for plants, fixing molecular nitrogen from the atmosphere and converting it to a form accessible to plants. Due to a complex of bacteria that produce carboxylic acids, amino acids, enzymes, phytohormones, antibiotics, and other substances, the biological product had a positive effect on plants and improved their adaptive and immune properties. A positive characteristic of the drug was the improvement of the soil structure, its air and moisture availability. Composition of the biological product: live bacterial cells of *Bacillus velezensis*, *Bacillus subtilis*, *Priestia megaterium*,

Agrobacterium pusense, *Agrobacterium salinitolerans*, *Paenibacillus polymyxa*; other useful microflora (lactic acid bacteria, enzyme producers); vitamins, phytohormones, amino acids, and other physiologically active substances. Total number of viable cells – $(0.5-1.5) \times 10^9$ CFU/cm⁵ (Groundfix phosphorus-potassium mobiliser, n.d.).

Azotohelp, KS – a biological product for stimulating plant growth and nitrogen fixation. Main action consists in fixing molecular nitrogen from the atmosphere by nitrogen-fixing bacteria and transferring it to a form accessible to plants, synthesising growth-stimulating substances that promote plant growth and development, increase immunity and resistance to stress factors, improve seed germination and nutrient absorption. Composition of the biological product: live cells of *Agrobacterium pusense* vitamins, phytohormones, amino acids, and other physiologically active substances. Total number of viable cells – not less than 1.0×10^9 CFU/cm⁵ (Azotohelp, KC, n.d.).

Soil samples from the experimental variants were selected in a row in two non-contiguous repetitions during the flowering phase (BBCH 65-69) of maize from a layer of 0-20 cm in accordance with DSTU 4287:2004 (2004). They determined the content of alkaline hydrolysed nitrogen by the Kornfield method DSTU 7863:2015 (2015), mobile compounds of phosphorus and potassium by the modified Chirikov method DSTU 4115-2002 (2002). The number of microorganisms of the main physiological and taxonomic groups (ammonifiers, amylolytics, pedotrophs, oligotrophs, oligonitrophiles, actinomycetes, micromycetes) was determined according to DSTU ISO 7847:2015 (2015) by surface (bacteria) and deep (micromycetes) seeding of soil suspension of the corresponding tenfold dilution into solid (bacteria) and liquid (fungi) nutrient media. The soil biogenicity index was determined as the sum of microorganisms of all the groups under study.

The orientation of microbiological processes in the soil was characterised by appropriate coefficients in accordance with regulatory documents and scientific sources DSTU 3750-98 (1998) (Andreuk *et al.*, 2001; Volkohon *et al.*, 2010): nitrogen mineralisation-immobilisation coefficient (K_{M-I}) were calculated by the ratio of the number of microorganisms that assimilate mineral and organic nitrogen; the coefficient of pedotrophy –

as the ratio of the number of pedotrophs and microorganisms that use mainly organic nitrogen compounds; the coefficient of oligotrophy – as the ratio of the number of oligotrophs and microorganisms that use mainly organic nitrogen compounds; the coefficient of transformation of organic matter of the soil – by the ratio of the number of microorganisms that assimilate mineral and organic nitrogen and the coefficient of mineralisation-immobilisation. In dynamics, the potential denitrification activity in rhizospheric soil was investigated by the rate of nitrous oxide emission using gas chromatographic methods (Volkohon *et al.*, 2015). The leaf surface area was determined by the linear method: the area was considered only in physiologically complete leaves (Palamarchuk & Solomon, 2021). The number of selected plants was 10 in four-fold repetitions.

Weather conditions in 2023-2024 corresponded to the trend of recent years regarding an increase in air temperature and a decrease in precipitation. Spring in 2023-2024 was characterised by elevated air temperatures and precipitation in April (+1.09°C, +4.06°C and +40.8 mm, +39.7 mm, respectively) and reduced in May (-0.9°C, -0.29°C and -33.5 mm, -61.7 mm to normal, respectively). The summer and autumn months of 2023 were characterised by high air temperatures in June, August, and September (+1.65°C, +5.31°C, and +3.41°C, respectively) and a lack of precipitation in June and September (-31.6 mm, -19 mm to normal, respectively), high precipitation in July (+38.1 mm), and sufficient precipitation in August (-0.5 mm). The summer and autumn months of 2024 were characterised by rising temperatures in June, July, and September (+2,08°C, +2,04°C, +3,19°C) and precipitation deficits in June, July, August, and September (-10.7 mm, -50.3 mm, -10.6 mm, and -42.7 mm, respectively). According to the hydrothermal coefficient of the HTC, there was a weak drought in 2023 (HTC – 0.9), and a strong drought in 2024 (HTC – 0.5). In general, the weather conditions of 2023 were more favourable for the development of maize productivity, compared to the dry conditions of 2024. Experimental studies of cultivated plants, including the collection of plant material, were in accordance with institutional, national or international guidelines. The authors adhered to the standards of the Convention on Biological Diversity (1992).

RESULTS AND DISCUSSION

According to the results of microbiological analysis of the soil, the influence of weather conditions on the number of microorganisms of the main physiological and taxonomic groups was noted. Thus, in a favourable 2023, the number of ammonifiers, amylolytics, pedotrophs, oligotrophs, and oligonitrophils was 3-4 times higher compared to the arid 2024. Notably, during the flowering period (BBCH 65-69) of maize under favourable weather conditions (hydrothermal coefficient (HTC)_{July} – 1.57) 2023 on the variants where Groundfix and

Azotohelp biologics were used (There was an increase in the number of ammonifiers, amylolytics, pedotrophs, oligonitrophils, micromycetes, and actinomycetes in the control variant, and a decrease in the number of oligotrophs. When applying liquid complex fertilisers (LCFs), the number of ammonifiers, amylolytics, pedotrophs, oligonitrophils, actinomycetes also increased compared to the control, and the number of micromycetes and oligotrophs decreased. However, the biogenicity of the soil both with the use of both biologics and LCFs was higher than in the control (Table 1).

Table 1. The number of soil microorganisms in the flowering phase (BBCH 65-69) of the maize hybrid DKC 3972 F₁ for the use of biologics, million CFU/g of soil (average for 2023-2024)

Fertilisers, biologics	Ammonifiers		Amylolytics		Pedotrophs		Oligotrophs		Oligonitrophils		Actinomycetes		Micromycetes		Soil biogenicity	
	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024
1. Control	12.9	3.1	12.3	4.4	18.1	6.6	42.7	10.0	13.5	2.2	0.24	0.36	0.114	0.067	99.5	26.3
2. LCF, 25 kg/ha	13.5	2.3	13.4	3.5	26.7	5.4	35.2	9.4	15.2	2.9	0.47	0.14	0.082	0.856	107.0	23.5
3. Groundfix, 1 l/ha	15.7	4.5	14.4	3.7	18.6	7.5	37.8	9.7	21.6	2.6	0.95	0.26	0.115	0.896	108.1	28.0
4. Azotohelp, 1 l/ha	14.6	4.1	12.6	3.2	23.0	7.2	27.3	8.6	23.2	3.7	0.39	0.14	0.157	0.108	101.0	26.8

Source: compiled by the authors

A similar pattern was observed in the arid conditions of 2024 (Varva village) in the flowering phase (BBCH 65-69) of maize (HTC_{July} – 0.2). Thus, using biologics Groundfix and Azotohelp, an increase in the number of ammonifiers, pedotrophs, oligonitrophils, micromycetes to the control variant was observed and a decrease in the number of oligotrophs. However, in contrast to favourable conditions, a decrease in the number of amylolytic microbiota and actinomycetes was found in typical arid chernozems. Although the biogenicity of the soil when applying biologics was also higher compared to the control. The use of LCFs caused a decrease in the number of microorganisms in all study groups, with the exception of oligonitrophils and micromycetes, compared with the control. The obtained results are consistent with the findings of a number of researchers on the significant impact of weather and climatic conditions and applied agricultural measures on the development of the soil microbial complex. I. Beznosko *et al.* (2022) noted that the number of microorganisms of the main ecological and

trophic groups inhabiting the rhizosphere of various agricultural crops depends on the phase of plant development, soil and climatic conditions, soil type, crop fertilisation system, and cultivation technology, while K. Bogati & M. Walczak (2022) indicated that arid conditions cause a decrease in the number and activity of the soil microbiome, disrupt the microbial structure, which leads to a decrease in soil fertility. A. Honchar *et al.* (2021) noted significant changes in the abundance and composition of the microbial complex of typical chernozem in the process of plant ontogenesis under the same conditions of agricultural technology of their cultivation. O.I. Zabolotnyi *et al.* (2024) noted that the use of biologics contributed to an increase in the maize rhizosphere compared to the control of the total number of bacteria by 10-30%, and micromycetes – by 7-20%, and L.M. Tokmakova *et al.* (2020) observed a 25% increase in the number of ammonium microorganisms when exposed to organic matter-destroying bacteria. The study by O.P. Siabruk *et al.* (2021) examined the effect of biologics on CO₂ emissions

and the microflora of the maize rhizosphere. The researchers found that the use of biologics facilitates microbiological activity in the root zone, which indicates an improvement in the microbial environment of the soil. L.O. Biliavska (2014) and O.I. Zabolotny & A. Zabolotna (2022) noted that the use of biologics contributes to the growth of the microbiota of the main ecological and functional groups in the root zone of maize and winter wheat plants (nitrogen-fixing, phosphorus-mobilising, pedotrophic, amylolytic), and to the increase in soil biogenicity.

Not only the number of microorganisms of various physiological and taxonomic groups, but also their ratio and direction of microbiological processes in the soil have a significant impact on the condition and fertility of the soil. In conditions of sufficient moisture in 2023, the processes of

destruction of organic nitrogen compounds prevailed in all variants of the experiment in soils. The intensity of mineralisation processes using biologics was close to the control variant and ranged from 0.86 to 0.92 with a control level of 0.95 (Table 2). However, the highest ($K_{M-I} = 0.99$) this indicator was in the variant with LCF 5-20-5, where the mineralisation and immobilisation processes were balanced. In conditions of drought, the intensity of mineralisation processes increased on the control and application of LCFs (to a greater extent), while the use of biologics helped to reduce their intensity. In the soil of the control variant and the variant with LCF ($K_{M-I} = 1.42$ and 1.52), the processes of immobilisation of mineral nitrogen compounds prevailed, and in variants with biologics – the mineralisation of organic nitrogen ($K_{M-I} = 0.82$ and 0.78) (Table 2).

Table 2. Directivity coefficients of microbiological processes in agrocoenosis of the maize hybrid DKC 3972 F₁ in the flowering phase (BBCH 65-69) with the introduction of biologics (average for 2023-2024)

Fertilisers, biologics	Mineralisation-immobilisation (K_{M-I})		Oligotrophy (K_o)		Pedotrophy (K_p)		Transformations of organic matter (K_{TOM})	
	2023	2024	2023	2024	2023	2024	2023	2024
1. Control	0.95	1.42	3.31	3.23	1.40	2.13	26.4	5.3
2. LCF, 25 kg/ha	0.99	1.52	2.61	4.09	1.98	2.35	27.1	3.8
3. Groundfix, 1 l/ha	0.92	0.82	2.41	2.16	1.18	1.56	32.8	10.0
4. Azotohelp, 1 l/ha	0.86	0.78	1.83	2.10	1.54	1.76	32.5	9.4

Source: compiled by the authors

Processes of microbial transformation of soil organic matter (according to indicators K_{TOM}) in all variants of the experiment were more active under favourable weather conditions in 2023 compared to the arid conditions in 2024. Simultaneously, the use of Groundfix and Azotohelp biologics in contrast conditions in 2023-2024 contributed to a more intensive course of microbiological processes of organic transformation compared to the control and the variant where LCF 5-20-5 was introduced. It is worth noting that in all the studied variants in 2023 and 2024, the soil microbiota was insufficiently provided with easily accessible nutrients (according to the indicators of K_o). However, when using Groundfix and Azotohelp biologics in favourable conditions in 2023, the shortage of nutrients before control for the soil microbiota was 27-45%, and in arid conditions in 2024 – 33-35%. It is important to note that when LCF 5-20-5

was added in rows during sowing under favourable conditions in 2023, the nutrient content also decreased by 21% relative to the control, and in dry conditions in 2024, on the contrary, it increased by 27%. Indicators of the pedotrophy coefficient ($K_p = 1.18-2.35$) indicated active absorption of mobile nutrients from soil reserves by the autochthonous microbiota of all variants of the experiment in 2023-24, to a greater extent with the use of LCF 5-20-5 ($K_p = 1.98$ and 2.35). Positive effects of biologics (including Groundfix and Azotohelp) on the microbiological activity of the soil were noted by D.O. Yakovenko & V.V. Boroday (2022), who recorded an increase in nitrogen fixation and mineralisation of organic matter. Similar results were obtained by V. Bolokhovskiy *et al.* (2024b), noting improvements in the rhizosphere environment and plant resistance to stress. T. Khomenko *et al.* (2022) indicated activation of the processes of

phosphatmobilisation and decomposition of organic residues. O. Tonkha, *et al.* (2019) noted the stabilisation of the soil biocoenosis and the overall improvement of its agroecological state.

The study by V.P. Patyka & O.V. Sherstoboyeva (2002) noted that denitrification is a set of processes in which nitrogen nitrates and nitrites are reduced to nitrogen gas compounds or molecular nitrogen by biological means. For a long time, it was believed that denitrification is carried out by highly specialised bacteria, in particular, *Paracoccus denitrificans* and *P. halodenitrificans*. However, this is a widespread ability of aerobic and facultative anaerobic bacteria, which use nitrates and nitrites as alternative electron acceptors in the respiration process. This is why the process is also called nitrate respiration, heterotrophic denitrification, or dissimilar nitrate reduction.

According to the results of the study, it was found that the introduction of biologics in the line had a positive effect on reducing nitrogen losses in the soil (Table 3). Thus, the potential activity of soil

denitrification with the introduction of Groundfix biologic in rows decreased in 2023 in the 5-7 leaf phase (BBCH 15-17) by 3.65 mmol N₂O/g of soil per day, and in 2024 – 2.92 mmol N₂O/g of soil per day and, respectively, in the phase of panicle ejection (BBCH 50-55) by 0.2, and 0.16, flowering (BBCH 65-69) 1.95, and 1.56. When using Azotohelp, there was also a decrease in potential denitrification, respectively, in the phase of 5-7 leaves by 2.73, 2.39, in the phase of panicle ejection by 0.5, 0.4 and in the flowering phase by 2.85, 2.18 mmol N₂O/g of soil per day, a similar effect of which was noted by V.V. Volkohon *et al.* (2015). In the variant where LCF 5-20-5 was applied, the activity of soil denitrification, on the contrary, increased to control at all stages of maize growth and development (Table 3). According to the results of agrochemical analysis, it was found that the exchange acidity in the experiment did not fluctuate significantly, was at the level of the control variant and did not significantly affect the growth, development and productivity of maize plants.

Table 3. Potential activity of soil denitrification in maize hybrid crops DKC 3972 F₁ with the introduction of biologics (2023-2024)

Fertilisers, biologics	Potential activity of soil denitrification mmol N ₂ O/g of soil per day					
	2023			2024		
	5-7 leaves (BBCH 15-17)	panicle ejection (BBCH 50-55)	flowering (BBCH 65-69)	5-7 leaves (BBCH 15-17)	panicle ejection (BBCH 50-55)	flowering (BBCH 65-69)
1. Control	11.36±0.4	16.48±1.1	9.35±0.8	8.99±0.8	13.08±0.9	7.38±0.3
2. LCF, 25 kg/ha	14.07±1.2	17.33±1.3	9.50±0.6	11.16±0.9	13.56±1.1	7.70±0.5
3. Groundfix, 1 l/ha	7.71±0.7	16.28±1.3	7.40±0.5	6.07±0.5	12.92±1.0	5.82±0.2
4. Azotohelp, 1 l/ha	8.63±0.9	15.98±0.6	6.50±0.6	6.60±0.4	12.68±1.2	5.20±0.3

Source: compiled by the authors

The variability of the content of alkaline hydrolysed nitrogen in the soil under favourable weather conditions in 2023 was low (0.9 %), and ranged from 100.1 to 108.5 mg/kg of soil. In the arid conditions of 2024, it increased slightly and amounted to 1.06%, that is, there were no significant changes in the content of alkaline hydrolysed nitrogen during the use of biologics. Microbiological processes that occur in the soil and are associated with the conversion of organic and mineral nitrogen compounds (mineralisation-

immobilisation, denitrification) had a significant impact on the content of mineral nitrogen in the soil. Thus, in the conditions of 2023-24, mineral nitrogen negatively correlated with the coefficient of mineralisation-immobilisation ($r = -0.88-0.68$) and denitrification ($r = -0.71-0.83$), which is quite logical and is explained in the first case by an increase in the intake of mineral nitrogen in the soil due to the direction of processes towards mineralisation, and in the second – a decrease in nitrogen losses with a decrease in denitrification

activity. In favourable conditions in 2023, a noticeable effect on the mineral nitrogen content was noted when using Azotohelp biologics, and in dry conditions in 2024 – for all fertiliser variants. However, the option where Azotohelp biologics were introduced was very different from others not only in a favourable 2023, but also

in a dry 2024 (Table 4). The content of mineral nitrogen increased by 3.2 and 13.4 mg/kg of soil, respectively, due to the functional feature of the bacteria that make up the preparation and are associative nitrogen fixators, promote nitrogen fixation and reduce the activity of the denitrification process.

Table 4. Agrochemical indicators of soil in crops of hybrid maize DKC 3972 F₁ in the flowering phase (BBCH 65-69) with the introduction of biologics (average for 2023-2024)

Fertilisers, biologics	Metabolic acidity, pH		Hydrolysed nitrogen, mg/kg		Mineral nitrogen, mg/kg		Mobile phosphorus, P ₂ O ₅ , mg/kg		Mobile potassium, K ₂ O, mg/kg	
	2023	2024	2023	2024	2023	2024	2023	2024	2023	2024
1. Control	5.5	5.5	102.2	115.5	12.1	13.6	126.0	146.2	113.8	97.5
2. LCF, 25 kg/ha	5.5	5.4	108.5	120.4	10.1	18.1	135.0	157.5	88.8	92.5
3. Groundfix, 1 l/ha	5.5	5.4	106.4	121.8	11.0	19.6	143.0	161.2	90.0	91.2
4. Azotohelp, 1 l/ha	5.6	5.5	100.1	120.4	15.3	27.0	128.8	130.5	92.5	96.2

Source: compiled by the authors

In favourable conditions in 2023, in the variant where Groundfix biologic was used, the content of mobile phosphorus increased by 17 mg/kg of soil relative to the control, and when using LCF 5-20-5 – by 9 mg/kg of soil. In dry conditions in 2024, the content of mobile phosphorus increased to the control with the introduction of Groundfix by 15 mg/kg and LCF 5-20-5 – 11.3 mg/kg. The increase in the content of mobile phosphorus in the soil is caused by a complex of phosphorus-mobilising bacteria that are part of the preparation and contribute to the solubilisation of phosphorus. However, the introduction of Azotochelp did not significantly affect the increase in the content of mobile phosphorus in the soil. The variability of mobile potassium content in the soil was at an average level ($V = 12.4\%$) in favourable conditions in 2023 and low ($V = 3.16\%$) in arid conditions in 2024. It should be noted that the content of mobile potassium in the soil during the flowering phase on the variants with LCF fertilisation and biologics decreased to the control variant, which was substantiated by the higher assimilation of maize plants. The decrease in the content of mobile potassium in the soil was more noticeable in favourable weather conditions in 2023 compared

to dry conditions in 2024, which was explained by its greater removal with the crop.

Under the influence of biologics, there were positive changes in the microbial coenosis of the soil, namely: the biogenicity of the soil, the amount of nutrients, and the activity of their transformation increased, while the intensity of mineralisation processes decreased. As a result, the amount of mineral nitrogen and mobile phosphorus in the soil increased and their assimilation by plants improved, which was reflected in an increase in the assimilation surface of maize crops (Table 5). Thus, when using the biological product Groundfix, the assimilation surface increased to control in 2023 and 2024, respectively, by 6 and 4.5 thousand m², dry matter of leaves – by 0.21 and 0.37 t/ha, Azotohelp, respectively, – by 10.1-12.8 thousand m²/ha and 0.62-0.69 t/ha. The use of LCFs also had a positive effect on the assimilation surface of leaves and their dry matter, but was less effective compared to biologics. The results obtained are consistent with the data of L. Kvasnitska *et al.* (2024), who noted that soil treatment with soil microbiological fertiliser Groundfix contributed to an increase in the leaf surface area of sunflower plants by 7% compared to the control.

Table 5. Photosynthetic activity of the maize hybrid DKC 3972 F₁ in the flowering phase (BBCH 69) with the introduction of biologics (average for 2023-2024)

Fertilisers, biologics	Area of the assimilation surface of leaves, thous. m ² /ha		Dry matter of leaves, t/ha	
	2023	2024	2023	2024
1. Control	45.3	40.4	1.92	1.74
2. LCF, 25 kg/ha	47.2	41.7	2.03	1.82
3. Groundfix, 1 l/ha	51.3	44.9	2.13	2.11
4. Azotohelp, 1 l/ha	55.4	53.2	2.54	2.43

Source: compiled by the authors

An increase in the photosynthetic apparatus of plants during the growing season had a significant impact on maize productivity. Thus, there is a direct relationship in 2023-2024 between the assimilation surface of leaves, dry matter of leaves, and yield ($r=0.74-0.67$ and $0.56-0.74$, respectively). The use of biologics in the row had a positive effect on

maize yields both in favourable conditions for plant growth and development in 2023 and in arid 2024. It is important to note that the productivity of the crop when using Groundfix in a row during sowing increased on average over two years by 0.5 t/ha compared to the control, Azotohelp, respectively, by 0.45 t/ha, and LCF 5-20-5 – 0.34 t/ha (Table 6).

Table 6. Maize DKC 3972 F₁ hybrid yield with the introduction of biologics (2023-2024)

Fertilisers, biologics	Yield, t/ha			
	2023	2024	average for 2023-2024	± to control
1. Control	10.64	6.98	8.81	0
2. LCF, 25 kg/ha	10.94	7.35	9.15	0.34
3. Groundfix, 1 l/ha	11.23	7.39	9.31	0.50
4. Azotohelp, 1 l/ha in	11.07	7.44	9.26	0.45
LSD _{0.95}	0.15	0.24	-	-

Note: LSD_{0.95} (the least significant difference) – the minimum difference between the two average values, which is considered statistically significant at 95 percent and is calculated over the years of research

Source: compiled by the authors

The results obtained coincide with the studies conducted by D.V. Litvinov & P.V. Petryk (2023), Ye.O. Yurkevych *et al.* (2023), according to which the introduction of Groundfix in the line during sunflower sowing at a dose of 0.75-1 l/ha increased the yield by 6.8-16.2% compared to the option without the introduction of the drug. The findings by V. Rotaru *et al.* (2021) and V. Ishchenko *et al.* (2022) indicated that the use of Azotofit at a rate of 0.5 l/ha in the agrocoenosis of winter wheat and 3 l/ha of sunflower contributed to an increase in grain yield by 15.8% and 10.4%, respectively, compared to the control, where biologics were not introduced.

Thus, the introduction of biologics has a positive effect on the agrochemical parameters of the soil, in particular, it helps to improve the supply of

nutrients (nitrogen, phosphorus, potassium), activates microbiological processes. As a result, the physiological state of plants improves, in particular, the assimilation surface of leaves increases, photosynthesis is activated, and nutrient absorption improves. This, in turn, ensured an increase in the biological productivity of maize and an improvement in the quality indicators of the crop.

CONCLUSIONS

It was established that the introduction of biologics in rows during sowing increased the activity of microbiological processes in the soil and positively affected the agrochemical indicators of typical chernozem, which, in turn, increased the assimilation surface of maize plants and increased crop productivity. Processes of microbial transformation



of soil organic matter (according to indicators K_{TOM}) in all variants of the experiment were more active under favourable weather conditions in 2023 compared to the arid conditions in 2024. Simultaneously, the use of Groundfix and Azotohelp biologics in contrast conditions in 2023-2024 contributed to a more intensive course of microbiological processes of organic transformation compared to the control and the variant where LCF 5-20-5 was introduced. The introduction of biologics Groundfix and Azotohelp, in comparison with the control, where biologics were not used, contributed to the growth of soil biogenicity, namely: an increase in the number of ammonifiers by 33% and 23%, respectively, pedotrophs – 8.18%, oligonitrophils – 39.70%, micromycetes – 17.48%, while increasing the amount of easily digestible nutrients by 30.40% and the intensity of transformation of organic matter of the soil – 57.50%, the intensity of mineralisation processes decreased by 23.27% and denitrification – by 21.30%. Positive changes in microbial coenosis improved the agrochemical parameters of the soil, namely: the content of mineral nitrogen increased by 8.3 mg/kg of soil when applying Azotohelp, and mobile phosphorus by 16 mg/kg of soil when using Groundfix.

Soil transformations under the action of biologics had a positive effect on the assimilation of nutrients by the crop and an increase in the photosynthetic activity of maize. Thus, when using the biological product Groundfix, the assimilation surface increased to control in 2023 and 2024, respectively, by 6 and 4.5 thous. m² of dry matter of leaves – by 0.21 and 0.37 t/ha, Azotohelp, respectively, – by 10.1-12.8 thous. m²/ha and 0.62-0.69 t/ha, which provided an increase in yield to the control with the introduction of Azotohelp 0.45 t/ha, and Groundfix – 0.5 t/ha. In further studies, it is advisable to continue comprehensive observations of the development of the soil microbiome under the influence of biologics and their impact on its fertility and productivity of agrophytocenosis in intensive cultivation technologies.

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Мікробіологічна активність ґрунту та її вплив на продуктивність кукурудзи за внесення біопрепаратів

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Анотація. Метою даного дослідження було оцінити стан мікробного ценозу та активність мікробіологічних процесів у ґрунті, їх вплив на агрохімічні показники чорнозему типового, асиміляційну поверхню листя кукурудзи та її насіннєву продуктивність за внесення біопрепаратів. У дослідженні було застосовано польовий метод для вивчення взаємодії об'єктів досліджень з природними факторами, лабораторний – для визначення мікробіологічних та агрохімічних показників, фотосинтетичної активності, а також математико-статистичний – для обробки експериментальних даних. Встановлено, що за внесення біопрепаратів Граундфікс і Азотохелп у сприятливих погодних умовах 2023 р., та посушливих 2024 р. збільшується порівняно з контролем чисельність мікроорганізмів переважної більшості агрономічно цінних груп, інтенсивність процесів трансформації органічної речовини ґрунту, а також знижується напруженість мінералізаційних процесів та потенційна активність денітрифікації, спостерігається зменшення дефіциту легкодоступних для мікробіоти елементів живлення. Встановлено високу обернену залежність між вмістом мінерального азоту в ґрунті і напруженістю мінералізаційних процесів у ньому ($r = -0,78$) та денітрифікаційною активністю ($r = -0,77$). Водночас відмічається прямий вплив асиміляційної поверхні листя та сухої речовини листя на урожайність ($r = 0,71$ та $0,65$ відповідно). Підвищується ефективність вирощування кукурудзи за внесення біопрепаратів Граундфікс та Азотохелп на 6 % та 5 % відповідно. Визначено, що використання біопрепаратів Граундфікс та Азотохелп у рядок під час сівби сприяє збільшенню біогенності ґрунту та оптимізації направленості мікробіологічних процесів у ньому, підвищенню доступності елементів живлення та їх засвоюваності, сприяючи при цьому росту рослин та інтенсифікації фотосинтетичної активності. Внаслідок позитивних

змін від застосування біопрепаратів Граундфікс та Азотохелп урожайність кукурудзи до контрольного варіанту підвищується відповідно на 0,50 та 0,45 т/га. Дані результати можуть бути використані для оптимізації інтенсивної технології вирощування кукурудзи, що сприятиме поліпшенню стану мікробного ценозу ґрунту, живлення рослин та підвищення врожайності кукурудзи

Ключові слова: мікробні препарати; чорнозем типовий; фізіологічні і таксономічні групи мікроорганізмів; активність денітрифікації; агрохімічні показники; урожайність