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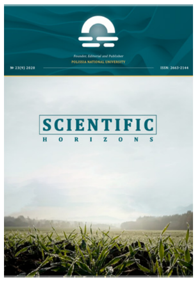

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Soil organic matter transformation under the influence of microbial agents and tillage in grain and oil crops in Southern Ukraine

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Abstract. This study aimed to evaluate the effectiveness of microbial agents in decomposing organic residues under different tillage practices in southern Ukraine from 2016 to 2020. Conducted at the Institute of Climate-Smart Agriculture, the research focused on dark-chestnut soil in a rainfed crop rotation involving winter wheat, grain

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sorghum, spring barley, sunflower, and a fallow field. Two factors were examined: microbial preparations and tillage (ploughing vs. ploughless). The Ecostern preparation, containing various bacterial strains and *Trichoderma* fungi, significantly accelerated winter wheat straw decomposition, achieving 45.9%-63.6% degradation within 90 days, a 31.4% increase over the control. The preparation Organic Balance, comprising *Bacillus subtilis* and other bacterial strains, maximised barley straw degradation at 80.1%. Sunflower residue mineralisation increased by 48.0%-55.5% with microbial treatments. These preparations also enhanced soil humus content by 0.06%-0.09%. The improved soil nutrient regime led to sorghum yield increases of 12.8%-45.3%, varying with tillage method. Spring barley yielded a maximum of 2.25 t/ha under ploughing with Organic Balance. Sunflower seed yields rose by 0.1-0.22 t/ha with ploughing. The accelerated organic matter transformation boosted soil biological activity, contributing to ecological sustainability. Ammonifying and nitrifying microorganism counts were highest with Ecostern and Organic Balance under shallow ploughless tillage, ranging from 19.82-25.87 and 7.31-12.76 CFU, respectively. Overall, the microbial preparations improved the soil's nutrient regime, resulting in significant increases in crop yields

Keywords: agroecosystem; cellulose decomposer; crop rotation; microorganisms; productivity; soil fertility; sustainability

INTRODUCTION

Ukraine faces the urgent task of increasing the efficiency of using both organic and mineral fertilisers. On irrigated land, environmental problems are largely associated with the use of large doses of mineral fertilisers. Reducing the chemical burden on the soil is possible by utilising atmospheric nitrogen and activating native soil resources. This goal can be achieved through the application of microbial preparations that stimulate nitrogen fixation from the atmosphere and mobilise phosphorus in the soil.

S. Stamenković *et al*. (2018) tell that the use of plant growth-promoting microorganisms (PGPMs) as a replacement for, or supplement to, conventional fertilisers can reduce their required dosage, improve ecological sustainability, and make agricultural practices more environmentally friendly. According to A. Panfilova (2021), one of the most significant roles in this regard is played by specific nitrogen-fixing bacteria, which, under certain crop and cultivation conditions, may replace the application of chemical nitrogen fertilisers. In addition, the soil biota facilitate the decomposition of plant residues into nutrients and stimulate the mineralisation of organic matter into mineral elements that are available for plant uptake and are subsequently accumulated in the soil. To promote the biological accumulation of nutrients in soils, specific microbial preparations are required. Some are applied by inoculating the soil, while others are used to treat seeds. Previous studies conducted in southern Ukraine by I. Bidnyna *et al*. (2021) confirm that microbial preparations can effectively compensate for the application of 40-60 kg/ha of mineral nitrogen and 15-30 kg/ha of phosphorus. Most microbial preparations contain strains of beneficial bacteria capable of fixing and accumulating atmospheric nitrogen in a form accessible to cultivated plants. These bacteria typically colonise and act in close proximity to plant roots, in the so-called rhizosphere. Inoculation of the rhizosphere with beneficial bacterial and fungal strains supports the ecological sustainability of the agroecosystem and enhances overall crop productivity. A. Aasfar *et al*. (2021) argue that the most widely used and effective soil-enhancing bacteria are nitrogen-fixing strains of Azotobacter, which significantly improve soil biological fertility and crop yields, contributing to sustainable agricultural development.

Soil microbiota and their activity determine the intensity, direction, and quality of organic matter transformation and nutrient cycling. J. Jansson and K. Hofmockel (2020) emphasise that this microbial activity plays a key role in influencing soil ecosystem stability and carbon sequestration, thus contributing to environmental sustainability and impacting greenhouse gas emissions and related climate concerns. The complex pool of soil organic matter, transformed by soil and rhizosphere microbiomes, is characterised by trophic diversity among microbial agents. It includes hundreds of heterotrophic bacterial strains with diverse traits and specific biological activities, including ecological transformation processes and patterns of soil organic matter immobilisation, as reported by M. Bohdan *et al*. (2021). P. Wu *et al*. (2021) also emphasise the importance of conducting robust and carefully designed studies on soil organic matter transformation under the influence of climate change and microbiome variation. Research into changes in chemical characteristics and metabolic rates provides essential insight into soil organic matter cycles, which, in turn, forms the basis for understanding the mechanisms underlying the transformation of complex organic compounds. A. Honchar *et al*. (2021) highlight the necessity of both theoretical and practical knowledge on this topic, as it determines the success of introducing external bacterial species into the soil microbiome and, consequently, affects the overall outcomes of crop symbiosis with new soil inhabitants.

Against the backdrop of ongoing climate change, agricultural science faces the challenge of transforming crop cultivation technologies based on the principles of climate-smart, environmentally friendly agriculture to ensure sustainable development and food security. It is particularly important to transition to climate-smart crop production in vulnerable arid and semi-arid regions, which are most severely affected by the intensification of global warming. For example, A. Teklu *et al.* (2024) report that climate-smart agricultural innovations, such as rational crop residue management, compost fertilisation, and efficient agroforestry practices, significantly improve food and nutrition security in Ethiopia, whereas soil and water conservation measures, among others, show inconclusive effects. In some cases, adaptation strategies prove insufficient to provide the necessary level of resilience, as found by P. Singh and H. Chudasama (2021) in their study conducted in the vulnerable semi-arid regions of India. Strategies for preserving and enhancing soil fertility form the foundation for effective adaptation of modern agriculture to current food security challenges and must ensure adequate resilience within agroecosystems, including the maintenance of soil fertility as a core parameter supporting crop production.

D. Pleissner (2020) notes that soil fertility is closely linked to the availability of essential nutrients for crops, a factor of both ecological and bioeconomic significance for the productivity and stability of agroecosystems. D. Ronga (2019) demonstrates the high efficiency and promising potential of microbial biofertilisers derived from specific algae, which can improve crop yields effectively without compromising environmental sustainability, biodiversity, or the economic viability of agrotechnologies. S. Rajan and M. Upsdell (2021) propose the introduction of *Acidithiobacillus* species into crop production to reduce the use of synthetic phosphorus fertilisers in modern agricultural practices, thereby enhancing the environmental safety of farming. Another promising form of microbial preparation is microbiological plant residue decomposers (e.g. stubble destructors and decomposers), which act by increasing the rate of stubble and straw decomposition and mineralisation, enhancing soil biological activity and, as a result, improving overall soil quality.

The main aim of this study was to evaluate the effectiveness and rationality of using microbial stubble destructors and cellulose decomposers to facilitate organic matter transformation in the soil under different tillage methods, including conventional ploughing and shallow surface tillage, within a typical rainfed crop rotation system in southern Ukraine.

MATERIALS AND METHODS

The study on the efficiency of microbial preparations for transforming soil organic matter was conducted under rainfed conditions in the south of Ukraine during the period 2016-2020, on the experimental fields of the Institute of Climate-Smart Agriculture of the National Academy of Agrarian Sciences of Ukraine, located in the Bilozerka District of Kherson Region (coordinates: 46°44′33″ N, 32°42′28″ E). Observations and measurements were carried out within a typical crop rotation involving the following sequence of crops: winter wheat → grain sorghum → spring barley → sunflower → fallow field. The experiment was designed as a systematic trial with three replications. The measured area of each second-grade experimental plot per treatment was 44 m^2 (plot configuration: rectangular, 11×4 m). The soil of the experimental field was classified as darkchestnut, medium loamy, with a humus content of 2.2% in the arable layer, determined using Tiurin's method (DSTU 4289:2004, 2005). The field capacity of the one-metre soil layer, determined using the soil saturation method (Karkanis, 1983), was 22.4%, while the wilting point was 9.5%. Groundwater was found at depths exceeding 10 metres. The study examined two factors: Factor A – soil tillage system, Factor B – microbial preparation. The experimental design is summarised in Table 1.

***Table 1**. Experimental design: influence of tillage systems and microbial preparations on soil organic matter transformation*

Factor A	Factor B
Plough tillage (P) for: winter cereal precursors – 2325 cm; winter cereals – 12-14 cm; grain sorghum – 25-27 cm; spring barley – 18-20 cm; sunflower – 2830 cm	Control (no preparation applied)
	Preparation 1 (Ecostern; application rate: 0.3-2.0 L/ha)
	Preparation 2 (Organic Balance; application rate: 0.251.50 L/ha)
	Preparation 3 (Bionorm; application rate: 1.5 L/ha)
Deep ploughless tillage with chisel cultivator (CP) for: winter cereal precursors – 23-25 cm; winter cereals – 12-14 cm; grain sorghum – 25-27 cm; spring barley – 18-20 cm; sunflower – 28-30 cm.	Control (no preparation applied)
	Preparation 1 (Ecostern; application rate: 0.3-2.0 L/ha)
	Preparation 2 (Organic Balance; application rate: 0.251.50 L/ha)
	Preparation 3 (Bionorm; application rate: 1.5 L/ha)
Shallow ploughless tillage with disc implements (DT) at a depth of 12-14 cm for all crops in the crop rotation.	Control (no preparation applied)
	Preparation 1 (Ecostern; application rate: 0.3-2.0 L/ha)
	Preparation 2 (Organic Balance; application rate: 0.251.50 L/ha)
	Preparation 3 (Bionorm; application rate: 1.5 L/ha)

***Source:** compiled by the authors*

The key features and composition of the microbial preparations studied are as follows:

1) Ecostern is a biodecomposer of plant residues with specific activity aimed at enhancing soil biological activity, providing ameliorative and anti-degradation effects. The preparation was produced by BTU-CENTRE (Biotechnologies of Ukraine). Its composition includes bacteria from the genera *Bacillus*, *Paenibacillus*, *Azotobacter*, *Enterobacter*, *Enterococcus*, *Agrobacterium*, and fungi from the genus *Trichoderma*.

2) Organic Balance is a systemic biological preparation containing a beneficial consortium of microorganisms, including cellulose decomposers, nitrogen fixers, and phosphorus mobilisers. It accelerates the decomposition of organic matter and the accumulation of humus in the soil, thereby promoting increased soil fertility and the restoration of soil health. The preparation is also produced by BTU-CENTRE, and its microbial composition includes *Bacillus subtilis*, *Azotobacter*, *Paenibacillus polymyxa*, *Enterococcus*, and *Lactobacillus*.

3) Bionorm is a cellulose decomposer with a broad spectrum of activity. It is produced by the Institute of Agroecology and Environmental Management of NAAS. Its microbial composition comprises a complex of beneficial fungi (*Trichoderma harzianum*, *Trichoderma lignorum*) and bacteria (*Pseudomonas fluorescens*, *Pseudomonas aureofaciens*, *Paenibacillus polymyxa*).

Laboratory investigations were conducted in the certified analytical laboratory of the Institute of Irrigated Agriculture of NAAS (now the Institute of Climate-Smart Agriculture of NAAS). The content of macronutrients in the above-ground plant biomass was determined as follows: total nitrogen – by the Kjeldahl method (DSTU ISO 11261:2001, 2003); phosphorus – by the colorimetric method using ascorbic acid; potassium – by the flame photometric method (DSTU 4114:2002, 2003). The organic matter content in the soil was measured using Tiurin's method (DSTU 4289:2004, 2005). The number of major soil microbiota groups was assessed in the 0-30 cm soil layer by culturing a soil suspension in nutrient media: ammonifying bacteria – in meat-peptone agar; nitrifying bacteria – in aqueous agar with ammonium magnesium salt. Following inoculation, the cultures were incubated in a thermostat at 28°C for 14 days. Colony growth was quantified, assuming each viable cell could form a separate colony. Microbiota abundance was expressed in colonyforming units (CFU) per gram of absolutely dry soil. Soil moisture content was determined by the gravimetric method (DSTU ISO 11465:2001, 2003). Microbiological analyses were performed in triplicate.

Statistical processing of the data was conducted using a two-way ANOVA procedure adapted for agricultural research, with Fisher's least significant difference (LSD) test applied to identify statistically significant differences between treatments (Agbangba *et al.*, 2024). All analyses were conducted at $P < 0.05$. The study was conducted following the standards of the Convention on Biological Diversity (1992).

RESULTS AND DISCUSSION

After harvesting, a substantial portion of organic matter in the form of shredded plant biomass and stubble remains on the field. The analysis of these residues revealed that the highest biomass levels were observed in the post-harvest period following winter wheat cultivation – 4.66-5.24 t/ha, while the lowest quantity of plant residues was recorded for spring barley – 2.35-2.50 t/ha (Fig. 1). The largest amount of plant residues was produced under ploughing tillage, totalling 15.88 t/ha. Chisel tillage reduced the quantity of plant residues by 7.6%, whereas shallow ploughless tillage led to a 13.4% reduction.

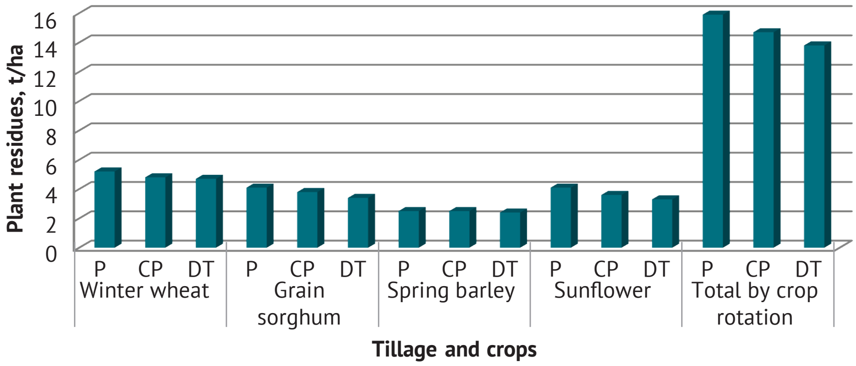
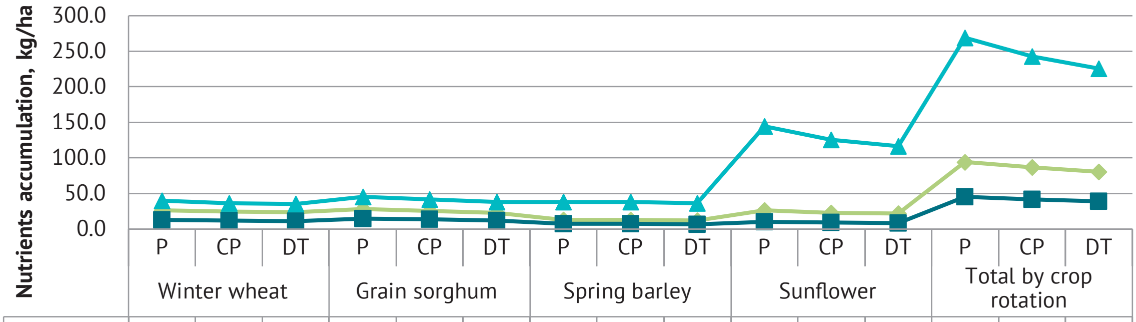


***Figure 1**. Effect of tillage on the yield of plant residues in the crop rotation*

***Source:** compiled by the authors*

The chemical composition and nutrient content of plant residues varied across crops. The highest levels of nitrogen (23.3-27.9 kg/ha) and phosphorus (12.3-147.8 kg/ha) were found in the organic biomass of grain sorghum, while the lowest were observed in the biomass of spring barley (12.2-13.0 kg/ha of nitrogen and 6.8-7.2 kg/ha of phosphorus, respectively). Over the entire crop rotation, the biomass contained

80.9-94.5 kg/ha of organic nitrogen, 39.0-45.5 kg/ha of phosphorus, and 226.1-269.1 kg/ha of organic potassium. The highest nutrient contents were observed under ploughing tillage, while the lowest were recorded under shallow tillage (Fig. 2). Varying tillage depths and methods led to differences in the rate of organic matter transformation. The most rapid transformation of plant organic matter was recorded under ploughing tillage, which is attributed to more effective shredding and incorporation into the soil (Table 2).



	Winter wheat P	Winter wheat CP	Winter wheat DT	Grain sorghum P	Grain sorghum CP	Grain sorghum DT	Spring barley P	Spring barley CP	Spring barley DT	Sunflower P	Sunflower CP	Sunflower DT	Total by crop rotation P	Total by crop rotation CP	Total by crop rotation DT
N	26.7	24.7	23.8	27.9	25.6	23.3	13.0	12.9	12.2	26.9	23.3	21.6	94.5	86.5	80.9
P2O5	13.1	12.1	11.6	14.8	13.6	12.3	7.2	7.2	6.8	10.4	9.0	8.3	45.5	41.9	39.0
K2O	39.8	36.8	35.4	45.9	42.2	38.3	38.5	38.2	36.2	144.9	125.6	116.2	269.1	242.8	226.1

***Figure 2**. Impact of soil tillage on the nutrient content in the biomass of cultivated crops*
***Source:** compiled by the authors*

***Table 2**. Influence of microbial preparations on the decomposition rate of plant residue in crop rotation over 90 days, depending on tillage systems, %*

Crop in the crop rotation	Microbial preparation (Factor B)	Soil tillage system (Factor A)		
		Plough	Ploughless	
			deep	shallow
Winter wheat	Control	23.0	21.9	18.7
	Preparation 1	63.6	53.9	45.9
	Preparation 2	59.7	49.4	41.6
	Preparation 3	56.1	47.6	40.0
Grain sorghum	Control	20.2	19.1	16.1
	Preparation 1	22.3	21.7	19.6
	Preparation 2	23.7	22.9	20.1
	Preparation 3	22.9	22.1	19.1
Spring barley	Control	31.5	29.0	24.7
	Preparation 1	55.0	50.1	47.3
	Preparation 2	55.3	51.9	47.6
	Preparation 3	53.9	49.7	46.7
Sunflower	Control	25.4	24.0	20.4
	Preparation 1	38.7	35.3	33.2
	Preparation 2	39.5	37.1	33.4
	Preparation 3	37.1	37.3	31.3
LSD_{05}, % for the studied factors: A – 1.9; B – 2.3				

***Source:** compiled by the authors*

In the case of shallow disc tillage, the shredded plant biomass is incorporated only into the topsoil, where moisture is rapidly lost, negatively affecting the conditions for the survival and activity of the soil microbial community. This, in turn, results in slower transformation of organic matter. Therefore, in this tillage variant, the decomposition and transformation of plant residues proceed significantly more slowly than under deep tillage conditions. Optimising the transformation of plant residues into soil organic matter within the crop rotation enhances soil biological activity and leads to an increase in soil humus content (Fig. 3).

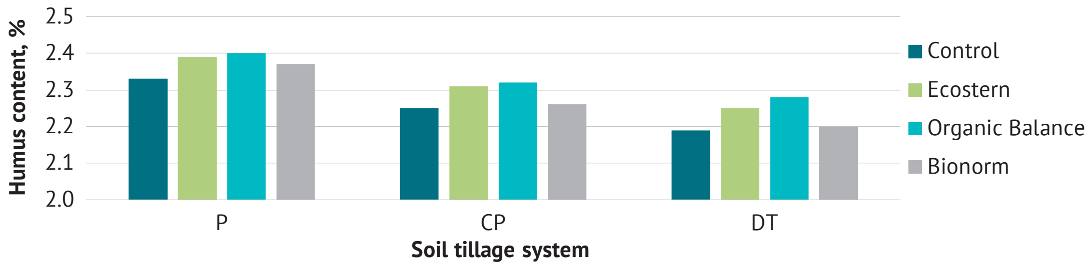


***Figure 3**. Soil humus content in the arable (0-30 cm) layer, depending on microbial preparations and tillage system, %*
***Source:** compiled by the authors*

It was found that deep incorporation of plant residues into the soil significantly increased organic matter content in the variants treated with the Ecostern microbial preparations (by 0.06%) and Organic Balance (by 0.07%-0.09%). However, the application of Bionorm did not lead to a significant increase in humus content. Under the shallow tillage system, the effect of Organic Balance on soil organic matter was greater (0.09% increase) compared with deep chisel and plough tillage (which showed only a 0.07% increase). The abundance of beneficial soil microbiota was influenced by the application of the studied microbial preparations. The number of ammonifying bacteria in the arable soil layer of the fallow field was slightly higher under the shallow tillage system (22.8125.87 million CFU), whereas under deep tillage systems, it ranged from 21.08 to 23.34 million CFU (Table 3).

***Table 3**. Number of ammonifying and nitrifying microbiota in the arable (0-30 cm) soil layer of the fallow field, depending on tillage systems and microbial preparations*

Soil tillage system (Factor A)	Microbial preparation (Factor B)	Number of microbiota in CFU per 1 g of absolutely dry soil					
		Ammonifying			Nitrifying		
		21 April	17 June	7 August	21 April	17 June	7 August
Plough	Control	21.08	17.34	16.69	10.78	8.07	7.63
	Preparation 1	22.60	21.71	21.51	11.98	10.16	9.03
	Preparation 2	23.34	22.17	22.47	12.53	11.17	9.34
	Preparation 3	22.03	22.01	22.14	9.94	9.44	7.63
Deep ploughless	Control	22.02	18.11	15.43	10.23	7.36	5.45
	Preparation 1	22.88	18.98	19.15	10.46	8.94	6.89
	Preparation 2	23.08	22.06	21.07	11.51	9.17	6.69
	Preparation 3	22.91	18.07	14.93	11.28	8.66	6.31
Shallow ploughless	Control	22.81	17.78	15.58	10.71	8.11	6.04
	Preparation 1	23.04	18.66	19.82	12.75	9.26	7.31
	Preparation 2	25.87	22.95	21.00	12.76	9.47	7.52
	Preparation 3	23.08	20.16	19.29	11.58	8.71	6.57
LSD_{05}	Partial differences:	A – 0.93; B – 0.90			A – 0.37; B – 0.32		
	Main effects:	A – 0.40; B – 0.34			A – 0.32; B – 0.27		

***Source:** compiled by the authors*

The application of Organic Balance had the strongest impact on the population of beneficial microbiota in the soil, exceeding the control by 3.08 million CFU per 1 g of absolutely dry soil under a deep tillage system. During the growing season, the number of ammonifying microorganisms decreased; however, the highest counts were recorded when Organic Balance was applied. During the growing season of grain sorghum, the population of nitrifying microorganisms in the soil was lower in all variants – by 15.6%-16.2% under deep ploughless tillage and by 19.6% under shallow ploughless tillage, respectively. The population of ammonifying microorganisms in the arable soil layer of spring barley crops increased by 4.8%-23.5% under ploughing with the application of microbial preparations, with the greatest increase observed when the Ecostern biopreparation was applied. Under deep ploughless tillage, the population of ammonifying microorganisms in the soil was 3.6%-44.2% higher than under ploughing. In the case of shallow ploughless tillage with Bionorm, the population of ammonifying microorganisms significantly exceeded that of the control variant (by 3.5%-7.7%). Changes in soil biological activity also affected the yields of the studied crops (Table 4).

Table 4. Crop yields, depending on tillage systems and microbial preparations

Microbial preparation (Factor B)	Tillage system (Factor A)			Average by Factor B
	Plough	Ploughless		
		deep	shallow	
Grain sorghum				
Control	3.32	3.01	2.90	3.08
Preparation 1	4.38	4.01	3.78	4.06
Preparation 2	4.76	4.36	3.81	4.31
Preparation 3	3.96	3.69	3.29	3.65
Average by Factor A	4.10	3.77	3.42	3.76
LSD_{05} t/ha: partial differences: Factor A – 0.23; Factor B – 0.20 main effects: Factor A – 0.09; Factor B – 0.11				
Spring barley				
Control	2.10	2.05	1.87	2.01
Preparation 1	2.16	2.13	2.10	2.13
Preparation 2	2.25	2.17	2.07	2.16
Preparation 3	2.21	2.10	1.99	2.10
Average by Factor A	2.23	2.12	1.96	2.10
LSD_{05} t/ha: partial differences: Factor A – 0.10; Factor B – 0.14 main effects: Factor A – 0.06; Factor B – 0.06				
Sunflower				
Control	3.31	2.95	2.66	2.97
Preparation 1	3.49	3.15	2.88	3.17
Preparation 2	3.51	3.17	2.90	3.19
Preparation 3	3.41	3.07	2.79	3.09
Average by Factor A	3.42	3.07	2.79	3.09
LSD_{05} t/ha: partial differences: Factor A – 0.10; Factor B – 0.14 main effects: Factor A – 0.06; Factor B – 0.06				

Source: *compiled by the authors*

Under ploughing, the highest yield of sorghum grain was obtained in the variants with Organic Balance application – 4.76 t/ha, and Ecostern application – 4.38 t/ha. Treatment with Bionorm resulted in lower sorghum yields, by 0.80, 0.73, and 0.63 t/ha, respectively. The switch to deep ploughless tillage reduced the effect of soil microbiota, with differences between the variants ranging from 0.35-0.67 t/ha. Under this tillage, Organic Balance produced a yield of 4.36 t/ha, and Ecostern – 4.01 t/ha. Under shallow ploughless tillage, sorghum yields were almost identical with Ecostern and Organic Balance treatments – 3.78-3.81 t/ha. Treatment with Bionorm led to a slightly lower yield, though it remained higher than that of the control. Under ploughing, all microbial preparations increased the yield of sunflower seeds by 0.06-0.20 t/ha, with the most significant increases recorded for Ecostern and Organic Balance. The application of Ecostern and Organic Balance under shallow disc tillage also resulted in an increase in sunflower yield by 0.22 and 0.24 t/ha, respectively.

Microbial preparations are essential for the successful transition towards biologisation in agriculture. M. Pylak *et al.* (2019) assert that current trends in the transformation of crop production based on sustainable, climate-smart organic agrotechnologies require microbial preparations to replace conventional chemical agents used for plant care and protection, as well as chemical fertilisers and soil ameliorants. P. Rowińska *et al.* (2024) confirm that among the various types of microbial agents used in agriculture, stubble biodestructors – in the form of plant residue decomposers and soil biological activity enhancers – are of great interest and importance in creating the conditions necessary for soil fertility preservation in conservation agriculture systems. The application of biological agents not only improves the overall fertility and ecological status of the soil but also contributes to increased yields and enhanced crop quality, thereby promoting the sustainability of agroecosystems and the environment.

The scientific and practical results of the present study are generally consistent with the findings of researchers from abroad. Studies by H. Chandra *et al.* (2020) have shown that soil fertility is directly related to the activity and vitality of beneficial soil microbiomes. Plant residues were found to transform into biochemical compounds available to plants over several years. This process depends on both abiotic and biotic factors, primarily soil moisture and temperature. E. Ampt *et al.* (2019) point out that the use of biological organic matter transformers accelerates the decomposition of plant residues and their incorporation into the soil, prevents unproductive losses through mineralisation and leaching, and contributes to enhanced soil fertility, increased crop yields, and improved quality of agricultural products.

In Ukraine, the majority of scientific studies have focused on the Ecostern microbial preparation. The study by O. Kovalenko (2023) reports that the use of this preparation within an integrated agrotechnology system resulted in a significant increase in the yield of spring barley varieties Hermes and Avatar. In addition, O. Kovalenko (2022) found that the treatment of plant residues with Ecosterm led to an increase in the population of cellulose-decomposing microbiota in the soil and promoted overall higher biological activity of beneficial soil microorganisms. Yields of winter wheat grain increased by 0.45-0.67 t/ha, depending on the preceding crop, as a result of Ecostern application as a stubble biodestructor. The study by O. Kuts *et al*. (2022) confirmed that a biological fertilisation system incorporating Ecostern as a stubble decomposer and Organic Balance as a source of beneficial bacteria resulted in the highest levels of nitrogen-fixing microbiota in the soil compared with conventional fertilisation systems. However, the yield increase under this system was not the highest when compared with organo-mineral fertilisation. The study by T. Khomenko *et al*. (2023) demonstrated that the application of Ecostern led to an increase in soil organic matter in the arable layer by 0.09%-0.11% compared to the control. V. Dudchenko *et al*. (2021) reported the beneficial effect of Ecostern on soil microbiota and soybean productivity within a rice-based crop rotation. A positive impact of biological preparation application was also noted in studies on legume crop productivity. Moreover, microbial agents were found to enhance the quality of pea and soybean seeds, as reported by I. Horodyska *et al*. (2021). A. Panfilova and Y. Byelov (2022) claimed that Ecostern application increased the availability of key nutrients in the soil, primarily due to improved mineralisation of precursor residues. It is important to note that the most favourable soil properties were observed under treatment with the microbial stubble decomposer in combination with plough tillage.

However, there are some inconsistencies in the current evidence regarding the application of stubble biodestructors. For example, V. Fomenko and A. Kaziuta (2023) found that the use of biological stubble destructors had negative effects on soil humus content and humification processes, in some cases even leading to dehumification. Therefore, the effectiveness of microbial biocomposers remains questionable, as their impact may vary significantly depending on soil type, tillage method, crop type, and other factors.

Concerning tillage systems, their impact is highly dependent on soil type and the general agroclimatic conditions of crop cultivation. There is some evidence in favour of no-till and minimal tillage practices for organic matter conservation, particularly in cropping systems where precursor residues are retained in the field. However, the difference, according to a study by B. Thapa *et al*. (2018), was statistically significant only for nitrogen (20.4%) and organic carbon (16.5%). The study provided strong support for the no-till system in terms of soil carbon sequestration compared to conventional deep tillage. M. Szostek *et al*. (2022) demonstrated that tillage systems significantly influence soil microbial activity, with the least favourable conditions observed under conventional ploughing, and the most favourable under simplified systems (e.g. shallow subsurface cultivation and disc harrowing). Similarly, the study by Y. Li *et al*. (2020) showed that reduced tillage and stubble retention led to higher microbial diversity and biological activity in soils. Soil biological activity was strongly influenced by both the depth and type of tillage, reaching its maximum under minimal and conservation tillage systems. This could be attributed to the increased microbial biomass observed under reduced tillage conditions. Different cropping patterns and tillage techniques influence nodulation, nitrogen fixation, and the composition of microbial communities. They also affect soil aeration, structure, and water-use efficiency. P. Angon *et al*. (2023) emphasise that conservation tillage systems are superior to conventional deep ploughing in maintaining optimal soil properties and fertility. Higher surface retention of crop residues, encouraged by conservation tillage, was directly associated with elevated levels of soil organic carbon, microbial biomass, potential nitrogen mineralisation, total nitrogen, and available phosphorus. No-tillage management promotes soil fertility, increases soil organic matter, and may even enhance the nutrient supply to crops through changes in microbial biomass mineralisation and nutrient immobilisation processes.

While these findings support reduced tillage, the study by B. Okorie and Y. Niraj (2022) offers contrasting evidence, highlighting improvements in overall soil fertility, as well as physical and chemical properties – including soil organic matter content – under conventional plough tillage. Nonetheless, in certain cases, ploughing may cause excessive soil loosening and loss of soil organic carbon. In such instances, no-till and minimal tillage practices prove more beneficial. Therefore, the influence of tillage systems on soil biological activity and fertility remains contentious, necessitating further robust investigation and meta-analysis.

CONCLUSIONS

The results of the study indicate that the most intensive transformation of wheat straw (45.9%63.6%) occurred following the application of the Ecostern microbial preparation, exceeding the control variant by 31.4%. The use of microbial organic matter-transforming agents increased the rate of grain sorghum residue decomposition by 5.9%-20.0%, with the Organic Balance biopreparation demonstrating the greatest efficiency. The intensity of barley straw transformation was 80.1% higher under the application of Organic Balance compared to the control. The treatment of sunflower plant residues with biodecomposer agents accelerated stubble transformation by 48.0%55.5%, with the degree of decomposition reaching 33.4%-39.5%. The application of microbial preparations promoted the immobilisation of organic polysaccharides in plant residues, increased microbial populations, and, consequently, facilitated the accumulation of organic nitrogen compounds within microbial biomass, thereby enhancing the return of organic matter to the biological cycle.

The establishment of a favourable soil nutrient regime through the use of biodecomposers resulted in increased sorghum grain yields by 12.8%-45.3%, depending on the tillage system. The greatest impact was observed with the Organic Balance preparation: yields ranged from 3.81 to 4.76 t/ha, whereas the control produced only 2.90-3.32 t/ha. Under plough tillage, the highest barley grain yield (2.25 t/ha) was also obtained with the application of Organic Balance. All biodecomposer agents led to increases in sunflower yield by 0.10-0.24 t/ha, with the highest yield (3.51 t/ha) observed under plough tillage combined with Organic Balance application. Overall, the use of microbial preparations under an optimal tillage regime offers a lever for efficient, environmentally sustainable regulation of soil fertility and biological activity, alongside notable improvements in crop productivity. Further research is needed to identify the most suitable microbial agents for specific agroecological conditions and agricultural practices.

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Трансформація органічної речовини ґрунту під впливом мікробіологічних препаратів і обробітку ґрунту на посівах зернових і олійних культур на півдні України

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Анотація. Дане дослідження мало на меті оцінити ефективність мікробних агентів у розкладанні органічних решток за різних способів обробітку ґрунту на півдні України в 2016-2020 роках. Дослідження проводилося на темно-каштановому ґрунті в богарній сівозміні з озимою пшеницею, зерновим сорго, ярим ячменем, соняшником та полем під паром, розташованими в Інституті кліматично орієнтованого сільського господарства Національної академії аграрних наук. Досліджували два фактори: мікробні препарати та обробіток ґрунту (полицевий чи безполицевий). Препарат «Екостерн», що містить різні штами бактерій та гриби *Trichoderma*, значно прискорив розкладання соломи озимої пшениці, досягнувши 45,9-63,6 % розкладання протягом 90 днів, що на 31,4 % більше, ніж у контролі. «Органік Баланс» з *Bacillus subtilis* та іншими бактеріальними штамами максимально прискорив розкладання соломи ячменю на 80,1 %. Мінералізація решток соняшнику збільшилася на 48,0-55,5 % після обробки біопрепаратами. Досліджувані препарати також підвищили вміст гумусу в ґрунті на 0,06-0,09 %. Покращення поживного режиму ґрунту призвело до збільшення врожайності сорго на 12,8-45,3 % залежно від обробітку ґрунту. Врожайність ярого ячменю становила 2,25 т/га за полицевої оранки та внесення препарату «Органік Баланс». Врожайність насіння соняшнику зросла на 0,1-0,22 т/га за полицевого обробітку ґрунту. Прискорена трансформація органічної речовини підвищила біологічну активність ґрунту, сприяючи його екологічній стійкості. Кількість амоніфікуючих та нітрифікуючих мікроорганізмів була найвищою за мілкого безполицевого обробітку ґрунту за внесення «Екостерн» та «Органік Баланс» і становила 19,82-25,87 та 7,31-12,76 КУО відповідно. Зрештою, мікробні препарати покращили поживний режим ґрунту, що призвело до значного підвищення врожайності сільськогосподарських культур

Ключові слова: агроекосистема; деструктор целюлози; сівозміна; мікроорганізми; продуктивність; родючість ґрунту; сталий розвиток