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BIODESTROYERS AS DRIVERS OF EVOLUTION OF SOIL ECOSYSTEMS

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Abstract

In conditions of intensive farming, post-harvest plant residues, in particular straw, become a significant logistical and environmental challenge. A promising alternative is the use of biological destructors, which provide targeted transformation of plant residues in the soil by stimulating biotic processes. Biodestructors not only accelerate the mineralization of organic matter, but also enrich the soil microbiome with beneficial, metabolically active microorganisms that inhibit the development of phytopathogenic and saprophytic species. The carbon released during the decomposition of straw is integrated into humification processes, stimulating the synthesis of humic and fulvic acids - key components of stable soil organic matter. In field conditions, a study was conducted on the effectiveness of different compositions of destructors (bacterial, fungal and combined bacterial-fungal) when applied to organic corn residues. Soil samples were analyzed according to generally accepted microbiological methods. The assessment of the direction of microbiological processes was carried out using ecological coefficients. The results showed that within 60 and 180 days after the introduction of biodestructors, the values of K_m , K_{ol} and K_{ped} in the experimental variants did not exceed 1, which indicates a balanced course of biotic processes and a harmonious ratio of synthetic and destructive mechanisms in the soil. For the control variant, these indicators were at or slightly above unity, which indicates a less stable state of the microbiological environment. The coefficient of transformation of organic matter 60 days after treatment with biodestructors exceeded the control indicators by 2.3–3.2 times, depending on the type of destructor. On the 180th day, the K of the experimental variants was 1.5 times higher than the control. This indicates a prolonged effect of destructors and effective conversion of organic matter throughout the vegetation cycle. Therefore, the formation of a favorable soil microbiome as a result of the use of biodestructors ensures not only the rapid processing of plant residues, but also contributes to the stabilization of physiological and metabolic processes in the soil environment.

Keywords: *destructors, microorganisms, mineralization, transformation of organic matter, ecological coefficients.*

The most significant property of soil, of planetary significance, is the closed biogeochemical cycles of most chemical elements of the Biosphere. In particular, these are the carbon and nitrogen cycles, which creates conditions for the simultaneous course of multidirectional chemical and

microbiological processes [1]. The fundamental driver of the global carbon cycle, participating in the processes of transformation of organic matter, including the degradation of plant residues, the synthesis of humic substances, the release and fixation of CO₂, CH₄ and other greenhouse gases, are soil microorganisms. It is known that 1 g of soil (0-20 cm) contains 10⁹-10¹⁰ prokaryotic cells (bacteria and archaea), 10⁴-10⁷ protists, about 100 m of fungal hyphae and 10⁸-10⁹ viruses. These values are converted into a biomass of prokaryotes exceeding 5 t/ha in some soils, with a biomass of fungi in the range from 1 to 15 tons. Soils also contain genetic diversity, with the total genomic diversity of bacterial communities from undisturbed grassland soils being three orders of magnitude greater than that of aquatic communities, with diversity ranging from thousands to millions of different prokaryotic species per gram of soil [2]. Microbiological processes in soils release more than 60 Gt of CO₂ annually, but are also able to retain a significant proportion of carbon through long-term forms of storage. Scientists [3] have shown that the main component of stable soil carbon (SOC) is microbial carbon (MCC). The share of MCC is approximately 50 % of SOC. However, understanding the spatial and temporal dynamics of MCC stocks is limited due to the variability of the microbiome and high sensitivity to weather conditions. A number of studies have shown the critical role that soil microorganisms play not only in the loss of organic carbon through microbial decomposition, but also in the formation and persistence of organic carbon (SOC), which is confirmed by the covariation between microbial biomass, necromass and SOC content. Although there are many ways in which microorganisms affect both the accumulation and loss of soil organic matter, microbial carbon use efficiency (CUE) is an integrative indicator that reflects the balance of these processes [4; 5].

In the agroecosystems of Ukraine, agriculture annually leaves about 50 million tons of straw, post-harvest or organic residues. From 1 hectare of agrocenosis, 5-7 tons of straw remain, corn - 12.5 tons, sunflower - up to 6 tons; in terms of organic matter content, 1 ton of straw is equivalent to 3.5-4 tons of manure. Usually, more than 20-40 % of straw in agroecosystems is not used at all or, at worst, is burned, causing irreversible damage to biota and the soil itself. In Ukrainian black soils, which account for 6.7 % of world reserves, the humus content at the beginning of the 20-th century was from 4 to 6 %, and at the beginning of the 21st century this figure did not exceed 3.2 %. It is known for certain that soil microorganisms are able to accumulate from 5 to 7 t/ha of organic matter in the soil of agroecosystems per year. Studies have shown that plowing straw and organic residues into the soil as an agrotechnical measure for 7-8 years increases the humus content in sod-podzolic soil by 0.24 %, and in southern black soil by 0.2 % [6-8].

Modern biological preparations that contain agronomically useful microorganisms and products of their cultivation help to solve the issue of straw and post-harvest residue conversion. Among biological destructors, according to microorganisms, two groups can be distinguished: bacterial and fungal. In Ukraine, in recent years, the biodestructors Polymix and Micocell have been widely used in farms.

Polymix – is a concentrated microbiological preparation based on spores of bacteria of the genus *Bacillus polymyxa*, *Bacillus megaterium*, *Bacillus licheniformis* and *Azotobacter croococcum* and their metabolic products: phytohormones of the auxin, gibberellin and cytokinin series, amino acids, vitamins. Total titer not less than 10⁹ CFU/g of the preparation.

Micocell – is a biodestructor (soil probiotic, remediator) of organic residues. A complex microbial-enzyme preparation to accelerate the process of humification and mineralization of plant residues and soil improvement. The biological preparation consists of a complex of strains of micromycetes *Trichoderma harzianum* and bacteria *Bacillus* ssp. (3 strains) and products of their metabolism: cellulolytic enzymes, phytohormones, antibiotics, vitamins.

In accordance with the above, the field experiment determined the direction of biological processes in the soil after applying the bacterial biodestructor Polymix, the fungal MycoCell, and their combination during the destruction of post-harvest corn residues.

Studies on the direction of microbiological processes in the soil with the introduction of destructors based on microorganisms were determined in the conditions of the Southern Forest-Steppe (Vinnytsia region, Ukraine) in a field experiment. It is worth noting that biological preparations-destructors were never used in these experimental areas.

It is worth noting that bio-destructors were never used in these experimental plots. Field experiment options: 1. Control (treatment of organic residues of the agroecosystem with water); 2. Urea-ammonia mixture liquid fertilizer (Urea Ammonium Nitrate UAN, $\omega = 26\%$); 3. Polymix 1 kg/ha + UAN 26; 4. MicoCell 1 kg/ha + UAN 26; 5. Polymix 0.5 kg/ha + MicoCell 0.5 kg/ha + UAN 26. The area of each experimental plot is 100 m², the repetition of each option is 3 plots. Bio-destructors were applied to organic corn residues, the working solution rate was 330 l/ha, after application, disking was carried out to a depth of 8 cm.

Soil samples were taken using conventional microbiological methods 60 (autumn) and 180 days (spring of the following year) after the application of destructors to the agroecosystem. The number of microorganisms of the main ecological-trophic and taxonomic groups was determined in the soil by the method of sowing limiting dilutions of soil suspension on agar nutrient media [9].

The direction of microbiological processes in the soil was determined by ecological coefficients [10]: coefficient of mineralization (K_{min}); coefficient of oligotrophy (K_{ol}); coefficient of pedotrophy (K_{ped}); coefficient of transformation of organic matter (K_{tom}). The results of the experimental studies were statistically analyzed using the Microsoft Excel program package. We determined the mean values (\bar{x}) and their standard deviations (SD). The level of significance selected for the study was $P < 0.05$.

Microorganism communities participate in the formation of all important soil properties, determine the intensity and direction of soil formation processes, including humus; form the biodynamic balance of the processes of synthesis and decomposition of organic matter and the availability of nutrients for plants. The ratio of numbers between different ecological-trophic groups of soil microorganisms and the composition of the microbiome directly depends on the plant species, its ontogeny, and the interaction between microorganisms and plants. It is believed that up to 50-70 % of the aboveground biomass is removed from the corn agroecosystem, and 30-50 % remains. In addition, in the overall balance of organic residues, roots account for about 10-20 % of the total biomass remaining in the soil of the agroecosystem. According to various data, the amount of the root system is approximately 1.5-2.5 t/ha, depending on the region of cultivation, variety, sowing density, etc.

In the field experiment, post-harvest residues of corn plants (straw, cobs, roots, etc.) were treated with biodestructors. The study of the number of microorganisms of the main ecological-trophic and taxonomic groups of the soil of the corn agroecosystem is presented in Table 1.

Based on microbiological seeding at 60 and 180 days after the application of the biodestructor, it was established that the number of microorganisms of the main ecological-trophic and taxonomic groups in the experimental variants was higher than in the control.

Microbiota study on the 60-th day of the experiment showed an increase in the number of microorganisms of all ecological-trophic and taxonomic groups relative to the control and the variant where nitrogen fertilizer was applied. The use of a complex of destructors contributed to an increase in ammonifiers by 2.2 times compared to the control, with mono-application of destructors the number of this group increased by no more than 2 times. It is worth noting that the number of streptomycetes and micromycetes increased in the experimental variants, which is naturally associated with the process of destruction of organic matter of straw left in the agroecosystem. The

number of the above-mentioned groups increased no more than 2 times compared to the control and 1.5–1.8 times compared to the application of nitrogen fertilizer. Therefore, the use of biological products contributes to the better development of microorganisms and, accordingly, an increase in their number than the mono-application of nitrogen fertilizers.

Table 1. The number of microorganisms of the main ecological-trophic and taxonomic groups of soil when using destructors*

Treatment	The number of microorganisms of the main ecological-trophic and taxonomic groups						
	Ammonifying, *10 ⁶ CFU/g soil	Bacteria that use mineral forms of nitrogen, *10 ⁶ CFU/g of soil	Oligonitrophiles, *10 ⁶ CFU/g soil	Pedotrophic, *10 ⁶ CFU/g soil	Streptomycetes, *10 ⁶ CFU/g soil	Micromycetes, *10 ³ CFU/g soil	<i>Azotobacter</i> , % of clumps
60 days							
Control	6.3±0.3	5.2±0.4	10.1±0.6	10±0.5	1.6±0.1	18.7±1.5	66
Urea Ammonium Nitrate (UAN)	10.1±0.4	7.5±0.5	11.3±0.7	12.1±0.6	2.03±0.1	20.3±1.6	58
Polymix	12.2±0.5	7.3±0.5	11.5±0.7	10.3±0.5	2.87±0.2	28.6±2.3	100
MicoCell	12.8±0.5	5.9±0.4	120.4±0.7	11.6±0.6	3.45±0.2	36.3±2.9	90
Polymix+MicoCell	13.9±0.6	6.2±0.4	14.5±0.9	11.2±0.6	3.1±0.2	31.4±2.5	100
180 days							
Control	5.9±0.4	7.1±0.5	11.6±0.6	13±0.9	1.98±0.1	12.8±0.8	76
Urea Ammonium Nitrate (UAN)	6.1±0.4	6.9±0.5	11.4±0.6	16.1±1.1	2.42±0.1	16.9±1	70
Polymix	6.9±0.4	6.3±0.4	12±0.6	13.8±1	3.05±0.1	25.7±1.5	100
MicoCell	7.8±0.5	6.9±0.5	12.7±0.6	13.1±0.9	4.61±0.2	31.6±1.9	100
Polymix+MicoCell	7.1±0.4	6.4±0.4	13.3±0.7	14.1±1	3.23±0.1	28.4±1.7	100

* The data in the table are the result of our own experimental research

For 180 days after the use of destructors, in the spring of the following year, the composition and number of microorganisms were determined in the soil before sowing soybeans. It was found that the number of microorganisms of the main ecological-trophic and taxonomic groups did not differ significantly from the results of the study on day 60, in the experimental variants the number of microorganisms was higher than in the control. Depending on the ecological-trophic group, the increase in the number of microorganisms varied from 1.2 to 2.5 times relative to the control. A higher level of the number of streptomycetes and micromycetes was noted when using the fungal destructor.

Thus, the use of destructors for the conversion of organic residues of agrocenosis, based on both bacterial strains and micromycetes, contributed to the activation of soil microbiota. An increase in the number of microorganisms of all major ecological-trophic and taxonomic groups was noted for

all variants of the experiment compared to the control and the use of nitrogen fertilizers. In addition, in the variant where nitrogen fertilizer was applied, only the number of bacteria that use mineral forms of nitrogen increased, and the other studied groups of microorganisms were at the same level as the control variant.

Ecological coefficients (K_{min} , K_{ol} , K_{ped} , K_{tom}) will allow us to characterize the functional state of the microbiome, the course of microbiological processes and the provision of microorganisms with trophic resources, and allow us to predict soil-forming processes (Table 2).

Table 2. Direction of microbiological processes in the soil when using destructors*

Treatment	Coefficient			
	Mineralization K_{min}	Oligotrophy K_{ol}	Pedotrophy K_{ped}	Transformation of organic matter K_{tom}
<i>60 days</i>				
Control	0.83	0.88	1.01	13.93
Urea Ammonium Nitrate (UAN)	0.74	0.64	0.93	23.7
Polymix	0.6	0.59	1.12	32.59
MicoCell	0.46	0.66	1.07	40.57
Polymix+MicoCell	0.45	0.72	1.29	45.1
<i>180 days</i>				
Control	1.2	0.89	0.89	10.8
Urea Ammonium Nitrate (UAN)	1.13	0.88	0.71	11.5
Polymix	0.91	0.91	0.87	14.46
MicoCell	0.88	0.86	0.97	16.62
polymix+micocell	0.9	0.99	0.94	14.98

* *The data in the table are the result of our own experimental research*

On the 60-th day of the study, the K_{ol} and K_{min} of the soil of the agrocenosis where destructors were used did not exceed 1, regardless of the study variant. K_{ol} for the experimental variants was 0.6-0.72; K_{min} ranged from 0.45 to 0.6. The indicators of these coefficients for the control variant were 0.88 and 0.83, respectively. Thus, on the 60-th day of the study, favorable conditions for the existence of microbiocenosis were formed in the agrocenosis, the availability of microorganisms was at a fairly high level, and the processes of synthesis of humus substances in the studied soil of the agrocenosis prevailed. The coefficient of pedotrophicity (K_{ped}) calculated for the soil of the agrocenosis where destructors were used for post-harvest residues was above 1. For the variant with the use of a bacterial destructor $K_{ped} = 1.12$, for a fungal one = 1.07, and for the complex bacterial+fungal = 1.29. This indicator for the control variant was 1.01, and for the variant with the use of mineral nitrogen fertilizer = 0.93.

Such values indicate that in the studied variants, decomposition of the introduced organic material is at a high level. And based on K_{ped} it is well observed that on the 60-th day of using the bacterial destructor, the indicator is higher than in the variant where the fungal one was used. This can be explained by the fact that bacteria occupy ecological niches more quickly because they use simple substances in their trophic pathways, unlike micromycetes, which, to ensure their vital activity, synthesize a complex of complex enzymes that are able to decompose polymers into monomers, and the construction of cell biomass itself is physiologically more complex than in prokaryotes. The

organic matter transformation coefficient was also calculated, which for the experimental variants was 2.3-3.2 times higher, depending on the destructor, compared to the control; and 1.4-1.9 times higher compared to the variant where mineral nitrogen fertilizer was used. So, on the 60-th day of the study of the soil of the agrocenosis where organic corn residues were treated with destructors, favorable conditions were created for the development of microorganisms of all ecological-trophic groups, the microbiocenosis itself was in a homeostatic state, and the process of destruction of organic material took place at a high level, as evidenced by the ecological coefficients.

On the 180-th day of the study, the K_{min} of the soil of the agrocenosis where destructors were used did not exceed, but approached 1 (Table 2). The soil mineralization coefficient of the control variant and the variant where nitrogen fertilizer was used was 1.2 and 1.13, respectively. It can be concluded that it was in the control soil and when nitrogen fertilizer was used that conditions were created when the microbiocenosis triggers the processes of destruction of soil substances, most likely this is due to the deficiency of organic carbon. That is, the soil microbiocenosis formed in these study options is not capable of decomposing organic corn residues with negligible activity. The oligotrophicity coefficient for all options was close to 1, which indicates the absence of nutrient deficiency. The pedotrophicity coefficient calculated for the soil of the agrocenosis of all studied variants was below 1 ($K_{ped.}$ was fixed within 0.71-0.94), that is, oligotrophic microorganisms that feed on low-molecular substances and indicate the last stages of the succession of microbial communities begin to dominate in the structure of the microbiocenosis. The calculated soil organic matter transformation coefficient on the 180-th day of the study was 2.5-3 times lower than the K_{tor} values for the experimental variants. Such indicators indicate that the transformation of organic matter still occurs in the soil of the agrocenosis, but at a lower level than on the 60-th day of the study. It should be noted that for all experimental variants K_{tor} ranged from 10.8 – the control variant to 16.6 – the variant with the use of a fungal destructor. Compared with the control variant in the variants where destructors were used K_{tor} was 1.3-1.5 times higher.

In the field experiment, the direction of microbiological processes in the soil was determined when using destructors on organic corn residues. It was found that during the study period of 60 and 180 days, the microbiocenosis was characterized by an increase in the number of microorganisms of the main ecological-trophic and taxonomic groups. In the soil where destructors were applied, an increase in the number of ammonifiers, streptomycetes, micromycetes and bacteria of the genus *Azotobacter* was recorded. The calculated ecological coefficients prove that the introduction of destructors into the soil on organic corn residues primarily allows the formation of a highly effective microbiome with the dominance of agronomically useful microorganisms. The formed microbiome contributes to the effective conversion of organic corn residues throughout the entire study period and allows balancing the course of all physiological and metabolic processes in the soil, which in turn contributes to the homeostatic state of the soil before sowing the next crop.

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БІОДЕСТРУКТОРИ ЯК РУШІ ЕВОЛЮЦІЇ ҐРУНТОВИХ ЕКОСИСТЕМ

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Анотація. В умовах інтенсивного землеробства післязбиральні рослинні залишки, зокрема солома, стають значним логістичним та екологічним викликом. Перспективною альтернативою є використання біологічних деструкторів, які забезпечують цілеспрямовану трансформацію рослинних залишків у ґрунті шляхом стимулювання біотичних процесів. Біодеструктори не тільки прискорюють мінералізацію органічної речовини, але й збагачують ґрунтовий мікробіом корисними, метаболічно активними мікроорганізмами, що пригнічують розвиток фітопатогенних та сапрофітних видів. Вуглець, що вивільняється під час розкладання соломи, інтегрується в процеси гуміфікації, стимулюючи синтез гумінових та фульвокислот – ключових компонентів стабільної органічної речовини ґрунту.

У польових умовах було проведено дослідження ефективності різних деструкторів (бактеріальних, грибових та комбінованих бактеріально-грибових) при застосуванні на органічних залишках кукурудзи. Зразки ґрунту аналізували за загальноприйнятими мікробіологічними методами. Оцінку спрямованості мікробіологічних процесів проводили за допомогою екологічних коефіцієнтів. Результати показали, що впродовж 60 та 180 днів після внесення біодеструкторів значення Кмін., Кол. та Кпед. у дослідних варіантах не перевищували 1, що свідчить про збалансований перебіг біотичних процесів та гармонійне співвідношення синтетичних та деструктивних механізмів у ґрунті. Для контрольного варіанту ці показники були на рівні або трохи вище одиниці, що свідчить про менш стабільний стан мікробіологічного середовища. Коефіцієнт трансформації органічної речовини через 60 днів після оброблення біодеструкторами перевищував контрольні показники у 2,3–3,2 рази, залежно від виду деструктора. На 180-й день Ктор дослідних варіантів був у 1,5 рази вищим за контрольний. Це свідчить про тривалу дію деструкторів та ефективне перетворення органічної речовини протягом усього вегетаційного циклу. Отже, формування сприятливого ґрунтового мікробіому в результаті застосування біодеструкторів забезпечує не лише швидку переробку рослинних залишків, але й сприяє стабілізації фізіологічних та метаболічних процесів у ґрунтового середовища.

Ключові слова: деструктори, мікроорганізми, мінералізація, трансформація органічної речовини, екологічні коефіцієнти.