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Z. O. DEHTIAROVA[1], PhD
Assistant Chair of the Farming and Herbology named after O.M. Mozheiko
e-mail: zinaidasamosvat@gmail.com ORCID ID: https://orcid.org/0000-0002-1055-4811
A. A. DYOMKIN[1]
Specialist of the University Development Center
e-mail: eclairoff@gmail.com ORCID ID: https://orcid.org/0000-0002-6500-821X
[1]*State Biotechnological University*
44, Alchevskikh Str., Kharkiv, 61002, Ukraine

IMPACT OF PROJECTIVE SOIL COVER WITH POST-HARVEST RESIDUES ON SOIL MICROBIOLOGICAL INDICATORS IN THE CONDITIONS OF THE LEFT-BANK FOREST-STEPPE OF UKRAINE

The transformation of crop residues is an important factor in shaping the spatial and functional structure of the soil microbial biome, crucial for enhancing soil fertility and ecological sustainability. Their application as a component of agrotechnology contributes to developing a stable, active, and diverse microbial community.

Purpose. To determine the effect of crop residue ground cover on the abundance of actinomycetes in soil.

Methods. Field experiments, laboratory-analytical procedures, and statistical methods.

Results. The data on the impact of various crop residues on the abundance of actinomycetes in soil presents. It was proven that residues of sunflower, corn, and soybean significantly enhanced microbiological activity, particularly increasing actinomycete numbers compared to the control without residues. The highest abundance of actinomycetes was recorded in soil with sunflower residues, indicating the high potential of this residue type to improve soil biological quality. An inverse relationship was found between actinomycete abundance and both soil moisture and temperature: optimal conditions were observed at 18.3% moisture and 26.0°C. The developed regression model demonstrated a moderate correlation between soil moisture and actinomycete abundance. The study emphasizes the importance of the chemical composition of crop residues, particularly the carbon-to-nitrogen (C:N) ratio, in creating favourable conditions for soil microbial development.

Conclusions. The use of crop residues in resource-saving farming systems is an effective measure to stimulate microbiological processes and improve soil fertility. Establishing the dependence of microbial activity on soil moisture and temperature makes it possible to optimize the water regime, reduce energy inputs for soil management, and ensure the sustainable development of the microbiota under climate change conditions.

KEYWORDS. *actinomycetes, crop residues, soil microbiota, soil temperature, soil moisture, stress conditions, tillage, corn*

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Introductions

Microorganisms play a crucial role in the soil ecosystem and in the cycling of key elements such as nitrogen and carbon. Plant residues are of great importance for their growth and reproduction, as they provide a nutrient-rich environment by increasing the organic matter content in the soil [1]. The microbiological properties of soil depend on the type and quan tity of crop residues post-harvest, as well as the soil conditions. For example, Y. Su et al. [2] reported that the soil microbiome responds more positively to the accumulation of corn residues compared to winter wheat residues. Changes in microbial biomass content in the soil are also influenced by soil temperature and moisture. Elevated temperatures negatively affect microbial productivity both in the soil and in agroecosystems as a whole. Under conditions of insufficient precipitation and increased temperatures (Hydrothermal Coefficient = 0.5–0.7), the population of soil microorganisms decreases by approximately 1.5 to 2.8 times. The application of organic and organo-mineral fertilizers mitigates the adverse effects of high temperatures on microbial productivity. Optimal soil moisture conditions positively affect microbial development (r = 0.66–0.79) and alleviate the negative impact of elevated temperatures [3].

Crop residues (such as stubble, leaves, and stems) serve as a source of organic matter that stimulates the activity of soil microbiota, including actinomycetes. Their abundance is influenced by the carbon-to-nitrogen (C:N) ratio, the presence of specific phenolic compounds or lignin, and the rate of residue decomposition. Changes in the quantitative and qualitative composition of root exudates within crop rotation systems lead to the reorganization of actively metabolizing microbial communities and affect the intensity of biochemical processes in the soil [4, 5, 6]. The study of the structure, abundance, and dynamics of ecological-trophic groups of microorganisms, as well as the functional activity of microbial communities in soils, provides valuable insights into changes in the trophic conditions of the soil biocenosis. Crop residues from soybean, corn, and sunflower significantly affect the development of actinomycetes in the soil, primarily due to changes in the composition of organic matter, microbial activity, and soil physicochemical properties. Actinomycetes are key soil microorganisms involved in the decomposition of complex organic compounds, the synthesis of antibiotics, and the formation of humus.

Actinomycetes play a key role in the decomposition of complex organic compounds such as lignin and cellulose found in plant residues. These aerobic soil microorganisms are essential for the humification of organic matter and the biosynthesis of antibiotics. The negative correlation between actinomycete populations and soil moisture can be attributed to several factors: limited oxygen availability under high-moisture conditions, which is critical for their survival; increased competition with other microorganisms, such as bacteria and fungi that thrive in moist environments; and the possible accumulation of metabolites toxic to actinomycetes under excessive moisture levels.

Purpose. To determine the impact of projective soil cover on microbiological indicators of soil under abiotic stress conditions.

Methods

The study was conducted in 2023–2024 at the Educational-Scientific-Production Center (ESPC) “Dokuchaievske Experimental Field” of the State Biotechnological University, located in the Left-Bank Forest-Steppe zone of Ukraine. The soil cover of the experimental field is represented by typical heavy loam Chernozem developed from loess-like loam. This soil is characterized by high reserves of plant-available nutrients, a significant humus content, and high biological activity. The arable soil layer (0–30 cm) is characterized by a humus content (according to Tyurin's method) of 4.9–5.1%, easily hydrolyzable nitrogen content (according to Kornfield's method) of 81 mg/kg of soil and mobile forms of phosphorus and potassium (according to Chirikov's method) amounting to 100 and 200 mg/kg of soil, respectively. The content of exchangeable cations is as follows: calcium – 37.8%, magnesium – 6.6%, sodium – 0.49%, potassium – 0.5%; the hydrogen content is 21 mg-eq./kg of soil. The soil reaction is characterized by a pH of 7.0 in aqueous extract and 5.2–5.6 in salt extract. Groundwater occurs at a depth of approximately 18 m [7].

The experiment was conducted with three replications. The plots were arranged sequentially. The area of the sowing plot was 750 m^2, and the accounting plot area was 100 m^2.

The experimental design included the following treatments:

- No plant residues (control)
- Projective soil cover with post-harvest soybean residues
- Projective soil cover with post-harvest corn residues
- Projective soil cover with post-harvest sunflower residues

The amount of plant residues on the winter wheat field was determined using the line-transect method. A measuring tape with markings at 10 cm intervals was used for this purpose. The sampling area was selected using a random sampling method. The measuring tape was placed at a 45° angle to the crop rows. A visual inspection of the presence of plant residues at the intersection points of the marked divisions was carried out along the tape. Each intersection of a marked point with plant residues was recorded as 1, and the absence of residues as 0. To improve the accuracy of the measurement method, repetitions were conducted on several lines placed at varying distances from one another across the field. The number of points where plant residues intersected the line was summed for each tape separately. The formula for determining the coverage fraction is as follows:

$$P = \frac{N}{T} \times 100\ \% \quad (1)$$

Where N is the number of points where the intersection with plant residues was recorded; T – the total number of points (the length of the ruler divided by the interval between markers).

The average coverage fraction is calculated for all measured lines:

$$\frac{\sum_{i=1}^{n} P_i}{n} \quad (2)$$

where n is the number of measured lines; P_i – the coverage fraction for each individual line.

Variants of soil tillage treatments:

1. Plowing with PLN-4-35 to a depth of 20-22 cm (control).
2. Local loosening with PCh-2.5 to a depth of 33-35 cm.
3. Chisel plowing with PCh-2.5 to a depth of 33-35 cm.
4. Disking with DMT-4 to a depth of 10-12 cm.
5. Chisel plowing with PCh-2.5 to a depth of 20-22 cm.

Microbiological investigations were carried out at the Soil Microbiology Department of the NSC "O.N. Sokolovsky Institute of Soil Science and Agrochemistry Research." In soil samples collected from the 0–25 cm layer, the abundance of actinomycetes was determined using the soil suspension plating method on starch-ammonia agar (SAA). Statistical analysis of the data was performed using analysis of variance (ANOVA), as well as correlation and regression analysis. All data were processed in the Colaboratory software environment.

Results and Discussion

According to the obtained results, the population density of actinomycetes was found to depend on both the presence and type of crop residues (Table 1). The highest abundance of actinomycetes was recorded in the variant with sunflower residues – 59.8% – indicating a high potential of these residues to stimulate microbiological processes in the soil. The incorporation of corn residues resulted in a 10% increase in actinomycete populations compared to the control (no residues), highlighting the effectiveness of corn as a source of organic matter. It is noteworthy that the distribution of corn residues was influenced by soil tillage methods.

In particular, the highest concentration of residues was observed following chisel plowing with the PCh-2.5 implement to a depth of 33–35 cm. In contrast, disking with the BD-2.5 implement to a depth of 10–12 cm finely fragmented the corn residues, leading to the near-complete absence of a protective mulch layer on the soil surface.

Table 1

Actinomycete Abundance in Relation to Soil Cover by Crop Residues

Crop residues	Soil moisture, %	Soil temperature, °C	Actinomycete abundance in Soil, %
No plant	19.0	30.7	45.0
Sunflower	18.3	26.0	59.8
Corn	18.0	26.7	55.0
Soybeans	18.1	23.3	51.1

Soybean residues contributed to a 6.1% increase in actinomycete abundance compared to the control, indicating a positive, though less pronounced, effect relative to sunflower and corn residues. This can be attributed to differences in the chemical composition of the residues, particularly the carbon-to-nitrogen (C:N) ratio, which affects decomposition rates and microbial activity in the soil. The lowest actinomycete counts were observed in the variant without crop residues, emphasizing the importance of organic inputs in sustaining soil microbial activity. The absence of organic matter suppresses the development of actinomycetes, which negatively impacts the overall condition of the soil environment.

The incorporation of plant residues into the soil is a key component of energy-saving agricultural technologies, as it not only improves the physicochemical properties of the soil but also enhances microbiological activity. The highest actinomycete density in the variant with sunflower residues demonstrates their effectiveness in restoring biological activity in the soil. Corn and soybean residues also support the stable development of microbial communities by providing a favorable habitat for soil microorganisms.

Elevated temperatures create adverse conditions for actinomycetes. At the same time, soybean residues had a moderate effect on actinomycete development, which is explained by their high nitrogen content and rapid decompo sition. However, compared to sunflower and corn residues, this effect is less significant due to the quick depletion of available substrates.

The highest actinomycete population – 59.8% – was observed at a soil moisture content of 18.3%, whereas the lowest – 45.0% – occurred at 19.0%. This suggests that excess soil moisture deteriorates conditions for actinomycete proliferation, as they tend to thrive under moderately moist, aerobic conditions. Figure 1 illustrates the relationship between actinomycete abundance (%) and soil moisture content (%). The key elements of the graph include experimental data points (blue markers) and a regression line (red dashed line), which depicts the trend between the variables. The coefficient of determination ($R^2 = 0.47$) indicates a moderate relationship between these variables. In other words, while there is a clear association, actinomycete populations are also influenced by other environmental factors such as temperature, soil chemical composition, or the presence of organic residues.

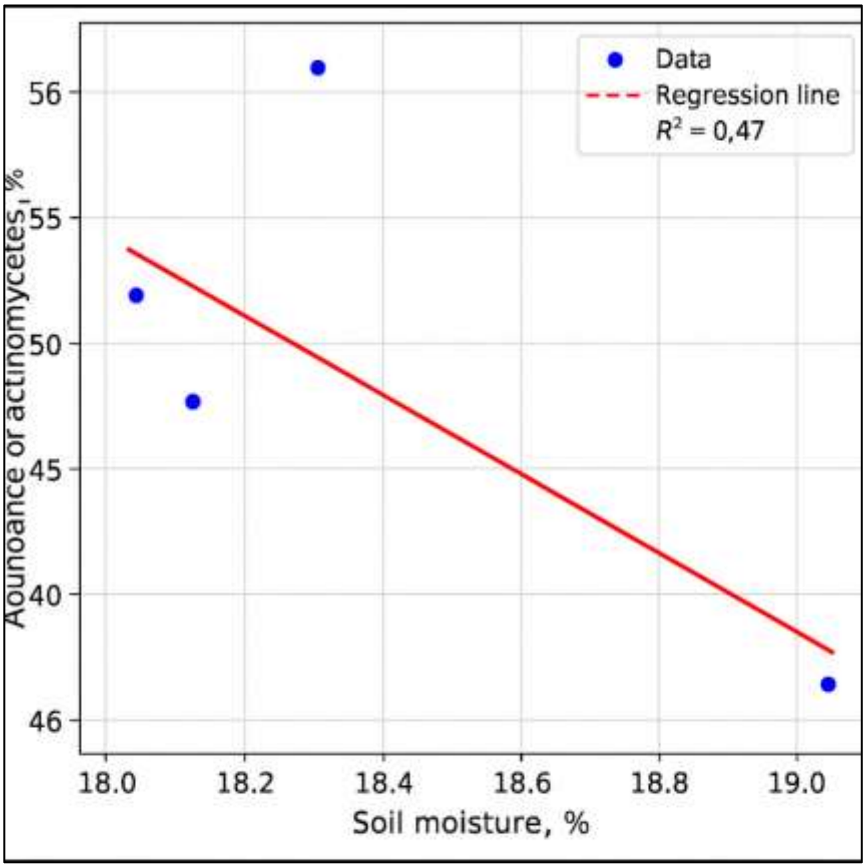

Fig. 1 – Relationship between microorganism abundance and soil moisture under various crop residues

The regression line reveals a negative trend: as soil moisture increases from 18% to 19%, actinomycete density gradually declines. This indicates that moisture levels exceeding optimal thresholds create unfavourable conditions for microbial development. The data points exhibit moderate variability around the regression line, suggesting that although the relationship is statistically significant, certain deviations exist. The highest actinomycete counts were recorded under the lowest moisture levels, supporting the hypothesis that their activity is strongly linked to aerobic conditions. This observation aligns with the findings of K. Kasman and D. Mance [8], who demonstrated that nitrogen mineralization by soil microorganisms is proportional to soil moisture content: when water content was increased in air-dry soil without reaching full equilibrium, nitrogen mineralization decreased linearly with rising water content.

Soil temperature is one of the key factors influencing biological activity in the soil. It has a decisive impact on the abundance of soil organisms, which play a crucial role in maintaining soil fertility and health. The abundance of actinomycetes exhibited an inverse relationship with temperature. The lowest population was recorded at the highest temperature of 30.7°C (Fig. 2). Temperatures of 26.0°C and 26.7°C in treatments with sunflower and corn residues, respectively, were found to be optimal for microbial development. In contrast, a lower temperature of 23.3°C in the soybean residue treatment slightly reduced the actinomycete population.

At a soil temperature of 23.3°C, the population of soil organisms reached 51.1%, indicating that this temperature was favourable for a significant portion of the soil biota.

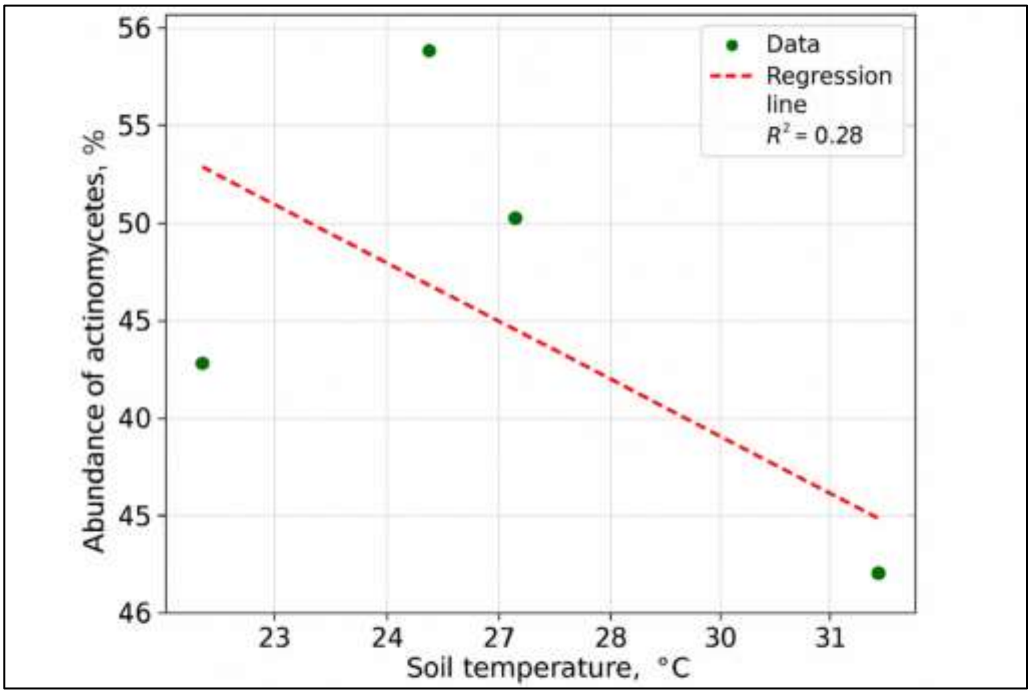

Fig. 2 – Relationship between microorganism abundance and soil temperature under different crop residues

As the temperature increased to 26.0°C, microbial abundance rose to 59.8%, suggesting that this is the optimal temperature range for active growth and reproduction. A further increase in temperature to 26.7°C led to a decrease in abundance to 55.0%, likely due to thermal stress experienced by the microorganisms, which negatively affected their activity. At the highest recorded temperature of 30.7°C, microbial abundance dropped to 45.0%, confirming that elevated temperatures are unfavourable for most soil biota, reducing both their activity and population levels. These results highlight the significant impact of plant residues on soil microbiological activity, a finding supported by both domestic and international studies. It is well established that organic residues from agricultural crops serve as a major source of carbon and energy for soil microorganisms. Their presence in the soil creates favourable conditions for the growth and biochemical activity of microbial communities.

A study by Ellanska et al. focused on changes in the microbial community of soil under the influence of silicon-containing mineral mixtures during the cultivation of various crops, including sugar beet, soybean, and corn. The results indicated that the abundance of specific ecological-trophic groups of microorganisms varied depending on the crop and the applied mineral mixture. The most significant shifts in microbial communities were observed under soybean and corn, particularly with the application of mineralized sapropels. A positive effect on the rhizosphere microbiota of sugar beet was observed when mixtures of raised bog peat with silicon-containing minerals and potassium silicate with silicon minerals and sapropel were applied. The mineralization processes of soil organic matter remained balanced, indicating the stability of the microbial community under the influence of the applied amendments.

Research by V. Rozhko et al. on the effect of agricultural crops on soil microbiological activity showed that a crop rotation including pea–winter wheat–buckwheat–corn led to a balanced microbial community, activation of enzymatic processes, and mitigation of soil fatigue. Similar findings were reported by L.V. Tsentilo, where, in typical chernozem soils, the application of organo-mineral fertilizers combined with plant residues led to an increase in the population of ammonifying bacteria to 4.7 million CFU/g, significantly exceeding the control (2.9 million CFU/g). Under the same conditions, enzymatic activity (urease, catalase) increased by 18–24%, further indicating the positive impact of plant biomass on microbial processes in soil.

In a study by L. Tokmakova and A. Trepach, it was found that the application of shredded plant residues stimulated the development of actinomycetes up to 1.2 million CFU/g, nearly twice that of the control. Microbial activity peaked within 3–4 weeks after residue incorporation, corresponding to the phase of active organic matter decomposition.

Our results align with international research. In a five-year field experiment, D. Yin et al. reported that corn residues increased microbial biomass carbon by 21–34% and enhanced the abundance of Trichoderma fungi and nitrogen-fixing bacteria. Additionally, microbial diversity (Shannon index) increased from 2.8 to 3.4, indicating the stabilization of the soil ecosystem. S. Lee et al. demonstrated that the diversity of cover crop residues positively influenced the structure of soil microbial communities. A mixture of three crops (pea, rye, and rapeseed) increased total microbial biomass by 42% compared to monocultural residues. This effect is attributed to the diverse carbon sources provided by the mixture, which supports a broader range of trophic groups.

However, as noted by L. Kerdraon et al., plant residues can act not only as a source of energy but also as a reservoir for pathogenic microorganisms. The authors describe the concept of «residue microbial ecology», suggesting that plant residues represent a transitional ecosystem where saprotrophs and potential pathogens coexist, which may have epidemiological implications in field conditions.

In the study by M.V. Patyka et al., the effect of plant residue transformation on the spatial-functional structure of the soil microbiome was analysed. Using metagenomic analysis, the authors found that straw incorporation altered the prokaryotic community composition, particularly increasing the abundance of cellulose-degrading microorganisms. These changes were accompanied by enhanced enzymatic activity, including catalase and dehydrogenase, indicating intensified microbiological processes in the soil. The findings align with previous studies showing the positive impact of plant residues on soil microbial activity. For instance, the incorporation of rye straw or organo-mineral fertilization combined with plant residues stimulated an increase in ammonifying bacteria and enzymatic activity.

Conclusions

Crop residues, particularly those from sunflower, corn and soybean, are effective in maintaining actinomycete populations, which in turn help to sustain and improve soil fertility. Sunflower and maize residues contributed to a high abundance of actinomycetes under the conditions tested. This can be attributed to the prolonged decomposition of cellulose and lignin, which provides a continuous substrate for these microorganisms.

The analysis of the relationship between soil microorganism abundance and soil temperature indicated that the optimal temperature range for their activity lies between 23.3 and 26.0°C. A gradual decline in microorganism abundance was observed as temperature increased, suggesting that higher temperatures create stressful conditions for these microorganisms.

A negative correlation between soil moisture and actinomycete abundance was observed, which can be explained by the biological characteristics of these microorganisms. Although the coefficient of determination ($R^2 = 0.47$) suggests a moderate strength of this relationship, the findings underscore the importance of maintaining optimal soil moisture levels to support the activity of actinomycetes, which play a crucial role in promoting soil fertility.

Conflict of Interest

The research was carried out under the support of the Ministry of Education and Science of Ukraine under Project № 2-24-26 of the Public Organization «Development of Measures to Ensure Sustainable Productivity of Agroecosystems under the Influence of Abiotic and Biotic Stress Factors», with State Registration № 0124U000457

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***Authors Contribution*:** all authors have contributed equally to this work

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ДЕГТЯРЬОВА З. О. [1], PhD
Асистент кафедри землеробства та гербології ім. О. М. Можейка
e-mail: zinaidasamosvat@gmail.com ORCID: https://orcid.org/0000-0002-1055-4811
ДЬОМКІН[1] О. О. [1]
Фахівець центру розвитку
e-mail: eclairoff@gmail.com ORCID: https://orcid.org/0000-0002-6500-821X
[1]*Державний біотехнологічний університет*
вул. Алчевських, 44, м. Харків, 61002, Україна

ВПЛИВ ПРОЕКТИВНОГО ПОКРИТТЯ ПІСЛЯЖНИВНИМИ РЕШТКАМИ НА МІКРОБІОЛОГІЧНІ ПОКАЗНИКИ ҐРУНТУ В УМОВАХ ЛІВОБЕРЕЖНОГО ЛІСОСТЕПУ УКРАЇНИ

Трансформація рослинних решток є важливим фактором формування просторово-функціональної структури мікробного біому ґрунту, що має значення для підвищення його родючості та екологічної стабільності. Їх використання як елемента агротехнологій сприяє формуванню стабільної, активної й різноманітної мікробної спільноти.

Мета. Визначити вплив проективного покриття рослинними рештками сільськогосподарських культур на чисельність актиноміцетів у ґрунті.

Методи. Польові, лабораторно-аналітичні, статистичний.

Результати. Представлено результати дослідження впливу різних видів рослинних решток на чисельність актиноміцетів у ґрунті. Доведено, що рослинні залишки соняшника, кукурудзи та сої значно підвищують мікробіологічну активність, зокрема кількість актиноміцетів, порівняно з варіантом без решток. Найвищий рівень актиноміцетів зафіксовано у ґрунті з рештками соняшника, що свідчить про високий потенціал цих решток у покращенні біологічного стану ґрунту. Результати показали наявність зворотної залежності між чисельністю актиноміцетів і вологістю та температурою ґрунту: оптимальні умови спостерігались при середній вологості (18,3 %) та температурі 26,0 °C. Побудована регресійна модель вказує на помірну силу зв'язку між вологістю ґрунту та чисельністю актиноміцетів. У дослідженні підкреслено важливу роль хімічного складу рослинних решток, зокрема співвідношення C:N, у формуванні умов для розвитку ґрунтової мікрофлори.

Висновки. Використання рослинних решток у системах енергоощадного землеробства є ефективним заходом для активізації мікробіологічних процесів і підвищення родючості ґрунту. Встановлення залежності мікробіологічної активності від вологості й температури ґрунту дає змогу оптимізувати режим зволоження, зменшити енергозатрати на обробіток і забезпечити сталий розвиток мікрофлори в умовах зміни клімату.

КЛЮЧОВІ СЛОВА: *актиноміцети, рослинні рештки, мікробіота ґрунту, температура ґрунту, вологість, стресові умови, обробіток ґрунту, кукурудза*

Конфлікт інтересів

Дослідження виконано за підтримки Міністерства освіти і науки України в рамках проекту № 2-24-26 Громадської організації «Розробка заходів щодо забезпечення сталої продуктивності агроекосистем під впливом абіотичних та біотичних стресових факторів», державна реєстрація № 0124U000457.

Автори заявляють, що конфлікту інтересів щодо публікації цього рукопису немає. Крім того, автори повністю дотримувались етичних норм, включаючи плагіат, фальсифікацію даних та подвійну публікацію.

Внесок авторів: всі автори зробили рівний внесок у цю роботу

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