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THE MICROBIAL ACTIVITY AND PHYTOSANITARY CONDITION OF SUNFLOWER CROPS DEPENDING ON THE LEVELS OF BIOLOGIZATION OF CULTIVATION TECHNOLOGY

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Abstract: The research was carried out from 2018 to 2021. The field experiments were conducted in four replications by using the split-plot design method. The study evaluated the following cultivation technology elements: A – sunflower hybrid: A1 – PR64F66 F_1; A2 – Tunca F_1; B – cultivation technology: B1 (traditional); B2 (biologized I); B3 (biologized II); B4 (organic); B5 (extensive). The research showed that during the growing season, under intensive sunflower cultivation technology, both the total colonization of the arable soil layer of the research plot and the amount of microflora by certain most principal groups decreased considerably compared to the variants where some elements of biologization or their complex application (organic cultivation technology) were implemented by 6.1–40.9%. The application of modern insecticides of organic origin in sunflower plant protection under biologized and organic cultivation technologies allows controlling a whole array of the most harmful phytophages and is not inferior to synthetic insecticides in effectiveness. The exception is the protection of the crop against owlet moth larvae, which, because of their biological and ecological characteristics, require an insecticide with more systemic properties, which are not characteristic of organic preparations with few exceptions. Biological preparations had no residual insecticidal or repellent effect on major crop pollinators. The application of pre- and post-emergence harrowing with harrows and rotary hoes and inter-row tillage in the system of the crop protection against weeds as a component of biologized and organic technologies for sunflower cultivation is as effective as soil and post-emergence synthetic herbicides.

Key words: sunflower, hybrid, biologization, microorganisms, disease.

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Introduction

Sunflower (*Helianthus annuus* L.) is a strategic oilseed crop of global importance in the agro-industrial sector, valued for its high-quality oil and nutritional value. However, its cultivation faces significant phytosanitary risks and is continually threatened by several soil-borne pathogens, including fungi such as *Sclerotinia sclerotiorum*, *Verticillium dahliae*, *Plasmopara halstedii*, and various species of *Fusarium* and *Phytophthora*. These pathogens lead to diseases such as root rot, wilt, and stem rot, which cause significant annual crop losses and economic damage. Combating these phytosanitary problems is extremely challenging, as the pathogens persist in the soil for long periods, and chemical control methods are often ineffective, environmentally harmful, and increasingly restricted (Tkalenko, 2015; Zhuykov et al., 2020; Zhuikov et al., 2022a; Brent and Hollomon, 1995).

The most common methods for improving the phytosanitary status of sunflower crops are: strict adherence to crop rotation, which reduces pathogen accumulation and improves soil health; implementation of a scientifically grounded plant protection system, involving chemical and biological preparations; adherence to the plant nutrient regime, which strengthens the plants' immune system; and cultivation of disease- and pest-resistant varieties and hybrids (Patika, 2001; Bazaluk et al., 2022; Zhuykov et al., 2024a; Bazaliy et al., 2019).

In the search for stable and effective protection protocols or for limiting spread, the soil microbiome is the main frontier for improving plant health and productivity. Soil is not just an inert growing medium but a complex ecosystem containing diverse microorganisms that directly influence the phytosanitary status of agricultural crops. Within this microbiome, specific functional groups play a key role in disease suppression and promoting plant growth. Thus, the use of antagonistic microorganisms through inoculation (*Pseudomonas*, *Bacillus*, *Trichoderma*) suppresses pathogens through competition, antibiosis, or parasitism. Symbiotic relationships with plant roots are also formed, improving the uptake of nutrients and water and increasing plant resistance to stress factors such as drought, frost, and the phytotoxic effects of pesticides (Zhuikov et al., 2022b; Vavrinevich et al., 2013; Zhuykov et al., 2024b).

The current studies by the Ukrainian and foreign scientists emphasize the inhibiting impact of reactants and metabolites of synthetic pesticides (mainly, fungicidal and bactericidal preparations) on the total amount and activity of soil microbiota (Aksenov, 2001; Bayrak, 2008; Volkogon and Dimova, 2010; Tkachuk, 2014; Pashkevich, 2009). The vast majority of modern groups of the above-mentioned pesticides are not selective in their effects on pathogenic and beneficial microflora. Therefore, while they control the amount of pathogenic agents in agricultural crops, they also pose a serious potential risk of bactericidal effects on microorganisms that directly participate in soil formation, perform mineralizing, nitrogen-fixing, ammonifying, and cellulose-decomposing functions, and act as antagonists to pathogenic microbiota (Anishin, 2012; Kysil, 2005; Klimenko, 2015; Brent and Hollomon, 1995).

If sunflower production is intensified, the intensity of the above-mentioned negative processes may increase, especially when sunflowers are returned too early to the same field in crop rotation, or when repeated planting or monocropping is practiced on farms in the region. The resulting increase in pesticide loads per hectare of sunflower fields creates more unfavorable conditions for the normal activity of microorganisms in the arable soil layer.

We present the results of the experimental research on the dynamics of microbiological soil activity intensity under different sunflower cultivation technologies, focusing on the main groups of micro-organisms involved in soil formation processes and responsible for different aspects of soil fertility formation.

Ammonifying microorganisms, also known as saprogenic bacteria, belong to a group of microorganisms that perform ammonification – the decomposition of organic nitrogen-containing (nitric) substances, releasing ammonia. They play a role in nitrogen cycling and plant nutrition. Ammonification occurs under both aerobic and anaerobic conditions. Aerobic and anaerobic microorganisms, decomposing protein, urine, chitin, organic fertilizers, humus, and similar materials can be ammonifying microorganisms. If, during the ammonification of proteins containing sulphur, hydrogen sulphide, indole and skatole are produced, this process is called putrefaction, and the microorganisms responsible are saprogenic bacteria. In addition to saprogenic bacteria, ammonification is also carried out by urobacteria, actinomycetes, and fungi. As a result of the activity of ammonifying microorganisms, the poorly available nitrogen in organic compounds from plant and animal residues is converted into a form accessible to plants. Ammonia released during ammonification is neutralized by soil acids producing ammonium salts, or nitrifying bacteria oxidize it to nitrogen (nitrate) and nitric (nitrite) acids. Most ammonifying microorganisms use protein as a source of carbon and energy, provided that there are no other substrates (such as sugars, spirits, or organic acids). Bacteria of the genus *Proteus*, as well as representatives of the genera *Bacillus*, *Pseudomonas*, and *Clostridium*, largely use proteins. Soil bacteria *Bacillus pasteurii* perform ammonification of carbamide. Representatives of the genus *Clostridium* decompose nitrogen-containing compounds to produce amines, further oxidizing other bacteria under aerobic conditions, releasing ammonia.

Oligonitrophiles are microorganisms, usually soil organisms, capable of growing under conditions with a small amount of bound nitrogen in the environment. Many of these organisms are diazotrophs, meaning they can fix atmospheric nitrogen.

Actinomycetes are prokaryotic, mycelial, gram-positive microorganisms that inhabit soil. As soil microorganisms, actinomycetes play an important ecological role. However, they attract researchers' attention mainly as one of the most important subjects in biotechnology. More than 60% of biologically active compounds are of microbial origin and two-thirds of antibiotics are metabolites of actinomycetes. Of these, 80% are synthesized by representatives of the genus *Streptomyces*. They also produce amino-acids, proteins, ferments, and other compounds. Nowadays, the search for new natural compounds with valuable characteristics, synthesized by actinomycetes, remains relevant. Actinomycetes are also important in agriculture due to their antagonistic characteristics and their ability to decompose compound substrates and degrade xenobiotics. The microbiological method for plant protection, which involves using actinomycetes and their metabolic products to suppress the development of phytopathogenic microorganisms, has significant potential.

Cellulose-decomposing bacteria are microorganisms, capable of decomposing cellulose. Important aerobic cellulose decomposers include representatives of the genera *Cytophaga* (*C. hutchinsonii*), *Sporocytophaga* (*S. mixococcoides*), *Sorangium* (*S. cellulosum*), *Archangium* (*A. gephyra*) and *Pseudomonas* (*P. fluorescens var. cellulosa*). However, the major role in cellulose decomposition under aerobic conditions is played by the fungi *Fusarium* and *Chaetomium*. Cellulose is also decomposed by *Aspergillus fumigatus*, *A. nidulans*, *Botrytis cinerea*, *Rhizoctonia solani*, *Trichoderma viride*, *Chaetomium globosus* and *Myrothecium verrucaria*.

Nitrifying bacteria are autotrophic microorganisms that obtain energy for their life activity by oxidizing ammonia to nitrates, which are known to be the most available form of nitrogen for plants.

Denitrifying bacteria convert nitrates to molecular nitrogen. All are aerobic and can oxidize organic matter using atmospheric oxygen, but under anaerobic conditions, they use the oxygen in nitrates as an electron acceptor. These bacteria are found in soil, water, and water body silt.

Nitrogen-fixing bacteria are capable of absorbing molecular nitrogen directly from the atmosphere. After these bacterial cells die, nitrogen returns to the ecosystem in a form available to plants. Without nitrogen-fixing bacteria, nitrogen available to plants would be washed out to the oceans, converted to its molecular form, and released into the atmosphere, resulting in the loss of soil fertility. The most widespread nitrogen-fixing bacteria are Rhizobium species, which form symbiotic relationships with the root systems of legume crops.

Material and Methods

Field trials on sunflower cultivation technology were conducted during 2018–2021 in the non-irrigated lands of the Farm "Vera" in the Hola Prystan district of the Kherson region. The experimental plots were located at the latitude 46°20'16.11"N, longitude 32°17'31.38"E, at an elevation of 9 m above the sea level.

The soil of the experimental plots was classified as dark-chestnut medium-loamy, and moderately saline, with a humus content of 2.34–2.60%. The content of mobile forms of mineral nutrients was as follows: nitrogen – 1.7–2.0 mg-eq per 100 g of soil; phosphorus – 4.9–6.5 mg-eq per 100 g of soil; potassium – 28–36 mg-eq per 100 g of soil. The pH ranged from 6.9 to 7.2. The soil has moderate natural fertility, which mainly depends on its nitrogen content.

The field experiments were conducted in four replications using the split-plot design method. The study focused on evaluating the following cultivation technology elements: A – sunflower hybrid: A1 – sunflower hybrid PR64F66 F_1 (bred by Pioneer); A2 – sunflower hybrid Tunca F_1 (bred by Limagrain); B – the level of biologization of the cultivation technology: B1 (traditional) – a traditional intensive zonal cultivation technology recommended by the originator for the conditions of the Southern Steppe of Ukraine, using mineral fertilizers and chemical plant protection products (PPP) to maximize the genetic potential of the hybrid; B2 (biologized I) – an intensive technology in which the plant care system replaces mineral fertilizers with biological fertilizers approved for use in organic farming. The multifunctional preparation TM “Eco-Growth” was used as an organic fertilizer; B3 (biologized II) – an intensive technology in which the plant care system replaces mineral fertilizers with biological preparations approved for use in organic farming, and herbicides are replaced with mechanical weed control operations. The preparations “ENZIM-Agro”, Gaubsin-FORTE, and Viridin (Trichodermin) were used as biological fungicides. The insecticide-acaricides TM “ENZIM-Agro” Entocid (Metarizin) and Aktarofit were used as biological insecticides; B4 (organic) refers to a technology in which the crop care system is based solely on the use of biological preparations (both fertilizers and pesticides); B5 (extensive) is an extensive (minimal) technology of crop cultivation, in which the system of crop care consists only of mechanical operations to control weeds, without using chemical or biological fertilizers and plant protection products.

The experimental plots were arranged using the split-block method. The total area of the experimental field was 1.2 ha, the total area of each quartic plot was 672 m², and the registered plot was 560 m². The experiment was replicated four times. Overall, the layout of the two-factor field experiment and the arrangement of the research plots followed this pattern.

The characteristics of the experimental hybrid: PR64F66 F_1: the originator company – Pioneer® (USA), simple two-lined highly oleic, the maturity group – medium-early (111–115 days), the actual production yield – 30.8 c/ha, the plant height – below the average (146 cm), convex seeds, the color – black-gray, the inflorescence – flat capitulum, the diameter – 15.4 cm, oil content – 51.1–52.3%, protein content – 16.0–17.2%, the weight of 1,000 seeds – 67 g. Disease and stress resistance: very high resistance to drought, excellent cold resistance, high resistance to lodging, resistance to 7 races of *Orobanche cumana* (A–G), resistance to various types of cinerea (white, ashy, dry, root), and tolerance to phomosis and phomopsis; Tunca F_1: the originator company – Limagrain® (France), simple two-lined hybrid, the maturity group – medium-early (110 days), the actual production yield – 29.5 c/ha, the plant height – medium (150 cm), elongated seeds, the color – black-gray, the inflorescence – flat capitulum, the diameter – 15.9 cm, oil content – 50.6–51.7%, protein content – 16.2–17.0%, the weight of 1,000 seeds – 73 g. Disease and stress resistance: high resistance to drought, excellent cold resistance, resistance to lodging, resistance to 7 races of *Orobanche cumana* (A–G), resistance to various types of cinerea (white, ashy, dry, root), and tolerance to phomosis and phomopsis.

During the research, we followed the generally accepted methods for conducting field experiments and performing laboratory experiments. The experiments included appropriate observations, measurements and analysis of soil and plant samples. All the records and observations were made in two non-contiguous replications.

The agricultural techniques used in the experiments, provided that the specified technological operation or its gradation was not a factor studied according to the experimental design, had the following pattern: winter wheat served as a pre-crop. After its harvest, disking was performed to a depth of 10–12 cm with the BDT-7. Fourteen days after the final disking, the stubble was plowed to a depth of 22–24 cm, followed by leveling with the KPE-3.8 (8–10 cm), and double pre-sowing tillage with the Lemken Compactor S unit. According to a preliminary agreement with the regional representatives of the companies that developed the sunflower hybrids, the crop seeds without pre-sowing incrustation with a fungicidal-insecticidal composition were purchased for the experiment. Pre-sowing treatment was carried out independently: in the intensive and biologized I technology variants, seeds were treated with a mixture of Cruiser 6 l/t (thiamethoxam 350 g/l) and Maxim 1 l/t (fludioxanil 25 g/l), in the biologized II and organic technology variants, seeds were treated with a mixture of biological preparations (Table 1) at the recommended rates, using 10 l/t of the working liquid. Mineral fertilizers (ammonium nitrate and granular superphosphate) were applied in the intensive and biologized II technology variants at the calculated rate of $N_{54}P_{46}$, average over the research years (40% of nitrogen and 100% of phosphorus for basic tillage, 60% of nitrogen for pre-sowing tillage). In the organic technology variant, biological fertilizers were used at the recommended rates. Sunflower seeds were sown in the middle of spring at a soil temperature of 6–7^{o}C at a depth of 5 cm using the wide-row method, with a row spacing of 0.7 m and a seeding rate of 55 thousand units/ha, using a SUPN-8 seeder, followed by post-sowing soil rolling with KKSH-3 rollers.

Table 1. The characteristics of biological preparations used in the variants of the experiment.

Preparation	Content	Methods and rates of application
Organic fertilizer "Eco-Growth"	Strains of the culture *Bacillus thermophiles*, *Bacillus subtilis*, phosphorus-mobilizing, nitrifying bacteria and chelate micro-fertilizer (51 g/l N, 12.0 g/l K_2O, 58 g/l MgO, 50 g/l SO_3, 6.5 g/l B, 12.5 g/l Cu, 12.4 g/l Fe, 12.0 g/l Mn, 0.2 g/l Mo, 6.4 g/l Zn, 0.1 g/l Co, 66.4 g/l amino acids, 67.8 g/l organic acids (succinic, malic, tartaric and citric), 3.3 g/l humic acids, 0.58 g/l fulvic acids, 0.0055 g/l phytohormones, 0.049 g/l of polysaccharides, vitamins, cytokinins, gibberellin compounds) pre-sowing seed treatment – 2 l/t; vegetative foliar feeding – 2 l/ha	pre-sowing seed treatment – 2 l/t; vegetative foliar feeding – 2 l/ha
Bio-fungicide Gaubsin-FORTE	Two strains of *Pseudomonas aureofaciens* with a cell titer of at least 4×10^9 CFU/ml	plant vegetative spraying – 2 l/ha
Biofungicide Viridin (Trichodermin)	Spores and mycelium of fungi of the genus *Trichoderma* spp. with a titer of not less than 1×10^8 CFU/ml and metabolic products – biologically active substances; pre-sowing seed treatment – 5 l/t; vegetative spraying of plants – 2 l/ha	pre-sowing seed treatment – 5 l/t; plant vegetative spraying – 2 l/ha
Biofungicide Entocid (Metaryzyn)	Spores of entomopathogenic fungi – not less than 2×10^8 CFU/ml	soil spraying for pre-sowing treatment – 5 l/ha
Biofungicide Actarofit	Complex of natural avermectins produced by the beneficial soil fungus Streptomyces avermitilis (abamectin – 50%, emamectin – 50%). The total content of toxins is not less than 1.8%	plant spraying – 0.2 l/ha

Source: Own description based on materials provided by manufacturers.

The care of sunflower plants involved the measures protecting the crop against a complex of pests when the economic threshold was exceeded. In the intensive and biologized I technology variants, weed control was achieved by applying the soil herbicide Triflurex at the rate of 3 l/t (triflurex 480 g/l) and the post-emergent herbicide Select at 2 l/ha (kletodim 120 g/l). In the biologized II, organic and extensive variants, weed control was carried out using mechanical methods, including pre- and post-emergent harrowing with weeders and rotary hoes, as well as inter-row tillage. Disease protection in the intensive and biologized I technology variants consisted of two vegetative treatments with the fungicide Amistar Extra at 1 l/ha (azoxystrobin 200 g/l + cyproconazole 80 g/l). In the biologized II and organic variants, treatments were performed with biofungicides (Table 1). Pest protection in the intensive and biologized I technology variants consisted of two vegetative treatments with the Ampligo 150 ZC insecticide at 0.3 l/ha, containing chlorantraniliprole 100 g/l and lambda-cyhalothrin 50 g/l. In the biologized II and organic technology variants, treatments were performed with bio-insecticides.

Vegetative plant treatment was carried out twice at the phase of sunflower development “3 pairs of true leaves” and “capitulum formation”. The rate of working fluid consumption in all the cases was 250 l/ha, with the preparations and tank mixture applied simultaneously 30 minutes before treatment. The crop was harvested by direct combining at the stage of full seed maturity using the self-propelled grain harvester John Deere 9660 STS. The data obtained were adjusted to basic moisture (7%) and 100% purity.

Sampling, preparation, and storage of soil samples for the investigation of microbiota were conducted in accordance with DSTU ISO 10381-6-2001 (DSTU ISO 10381-6-2001, 2006).

In the samples collected from the experimental plots, the abundance of the main ecological-trophic groups of microorganisms was determined by microbiological methods (Conrad, 1996; Gerhardt, 1981; Volkogon et al., 2010; Volkogon et al., 2011) by seeding diluted soil suspensions onto nutrient media. The abundance of the following groups of microorganisms was determined: ammonifiers – microorganisms that predominantly use organic compounds as sources of nitrogen and carbon (their abundance was determined by seeding aqueous dilutions of the studied soil onto agarized meat-peptone medium); immobilizers of mineral nitrogen – microorganisms that assimilate predominantly mineral nitrogen compounds (if mineral fertilizers are absent in the soil, these microorganisms begin to develop after the ammonification of organic compounds occurs); their abundance was determined by seeding soil dilutions onto agarized starch-ammonia medium; nitrogen fixers – bacteria capable of assimilating nitrogen from the air, whose abundance was determined by the method of soil crumb overgrowth on semi-liquid nitrogen-free Ashby’s medium, followed by testing for the ability of nitrogen fixation (gas chromatography test for acetylene reduction); denitrifiers – bacteria capable of reducing nitrates to N_2O, NO, and N_2, whose abundance is determined by seeding soil dilutions into liquid Giltay’s medium with KNO_3 and after incubation in a thermostat, testing for nitrate reduction is performed using the Griess reagent (nitrate test); pedotrophs – microorganisms capable of growing on soil agar, whose abundance was determined on agarized aqueous soil extract. These indicators are often used as an equivalent to the total abundance of microorganisms in the soil; micromycetes (microscopic fungi) – abundance was determined by seeding soil dilutions onto acidified agarized Czapek’s medium or onto wort-agar; cellulolytic bacteria – abundance was determined by seeding soil dilutions into liquid Imshenetsky-Solntseva medium with strips of filter paper. The results were expressed as the number of CFU per 1 g of absolutely dry soil. The potential activity of soil-biological processes was also determined. This activity was measured in soil samples by creating optimal temperature, moisture, and an excess of nutrient sources, resulting in obtaining an indicator of the maximum possible level of activity for the studied process.

Accountings of soil and plant pests were conducted with consideration of modern systems of soil tillage, application of fertilizers and plant protection products (Demenko and Yemets, 2020). During pest sampling from the soil, square samples of 0.25 m^2 (50×50 cm) were laid out. Soil from each sample was removed layer by layer: the first layer to a depth of 5 cm, and each subsequent layer to a depth of 10 cm. Insects were collected, counted and identified separately for each layer. Phytophage accounting was conducted by counting individuals per 1 m^2 or by the number of damaged plants (at the early stages of crop development). Observations were made before and after the application of the insecticide, as well as at 5, 10, and 20 days post-application, in clear, sunny weather between 11:00 and 13:00. Cabbage flea beetles were counted using measuring frames with an area of 0.25 m^2 at 16 points on the plot. The species composition of phytopathogens was determined visually using an atlas, and their distribution was assessed by the percentage of damaged plants and the percentage of damaged area of the assimilation apparatus at 10 points on the plot. The intensity of flowering plant visitation by honey bees was measured using glue traps.

The experimental data for sunflower were analyzed using the standard procedure of ANOVA within the MS Excel software. The significance of the differences was confirmed at the 95% reliability level.

Results and Discussion

The experimental data show that during the growing season, under intensive sunflower cultivation technology, both the total colonization of the arable soil layer in the research plot and the total amount of microflora in the main groups decreased significantly compared to the variants where some elements of biologization were used or where their combined application was implemented (organic cultivation technology) (Table 2).

Due to a lack of negative pesticide pressing on the agrocenosis and the additional supply of CFU by certain groups of soil microbiota, during the period of observation, there was a positive trend in the number of microorganisms in the variants of biologized I and II and organic technologies for sunflower cultivation. Organic management practices have a positive impact on microbial population sizes, as confirmed by the results of other studies. Specifically, organic farming systems lead to significantly greater microbial biomass (by 59%) and activity (by 19–84%, depending on the indicator) compared to conventional systems (Lori et al., 2017). Long-term organic farming increases both the quantity and diversity of microbes (Tsentilo, 2019). This indicates a more stable and resilient ecosystem capable of performing plant-beneficial functions more effectively (Hartmann et al., 2015; Geisseler and Scow, 2014).

On average, according to factor A, from the stage of “the first set of true leaves” to the stage “complete seed maturity”, the total colonization of 1 g of completely dry soil by aerobic species increased as follows: under biologized I – by 8.3%, biologized II – by 6.7%, organic – by 8.0%; ammonifying species – by 6.1%, 6.2% and 5.7%, respectively; oligo-nitrophiles – by 14.7%, 12.9% and 10.9%; nitrophiles – by 18.5%, 17.9% and 19.2%; cellulose-decomposing – by 40.9%, 28.0% and 28.0%; nitrifying – by 23.9%, 26.7% and 28.9%. For the group of actinomycetes, we observed a decrease in soil colonization during the growing season in the biologized and intensive technology variants, which is considered a positive effect, since this group is mostly represented by pathogenic species that cause crop diseases, particularly in sunflower (Table 2).

Table 2. Dynamics of micro-biological activity of 1 g of completely dry soil under different sunflower cultivation technologies, CFU/g dry soil (average for 2018–2021).

Cultivation technology	Stage of plant development						
	First set of leaves						
	aerobic species, mln.	ammonifying, mln.	oligo-nitrophiles, mln.	actinomycetes, mln.	nitrophiles, mln.	cellulose-decomposing, thous.	nitrifying, thous.
Traditional	17.5	16.6	12.9	1.0	15.1	1.3	7.1
Biologized I	18.9	17.0	16.2	1.1	15.0	1.3	8.3
Biologized II	19.5	17.2	16.9	1.0	15.6	1.7	8.5
Organic	19.6	17.6	17.2	1.1	15.4	1.8	8.6
Extensive	18.0	16.9	12.5	1.1	13.0	1.1	7.5
Cultivation technology	Stage of plant development						
	Complete maturity						
	aerobic species, mln.	ammonifying, mln.	oligo-nitrophiles, mln.	actinomycetes, mln.	nitrophiles, mln.	cellulose-decomposing, thous.	nitrifying, thous.
Traditional	10.3	11.3	8.9	0.7	9.7	0.7	5.1
Biologized I	20.6	23.0	19.0	0.9	18.4	2.2	10.9
Biologized II	20.9	23.3	19.4	0.8	19.0	2.3	11.6
Organic	21.3	23.7	19.3	0.9	19.2	2.5	12.1
Extensive	11.9	14.2	10.7	0.6	11.8	0.8	5.9

Note: average values for both tested hybrids. All the experimental data obtained showed significant differences ($P < 0.05$).

Conventional technologies suppress the development of microbiota, as clearly shown in our research. The results obtained in studies (Tian et al., 2015) confirm that high doses of nitrogen can inhibit certain microbial groups, particularly cellulose-decomposing bacteria and actinomycetes, due to soil acidification. This indirectly explains why biologized systems perform best in this regard.

Analysis of the dynamics of soil microbiological activity across the variants of traditional and extensive cultivation technologies showed a drop in the number of

CFU for all groups, except for actinomycetes. This process was more intense under the traditional cultivation technology, which can be explained by the application of synthetic pesticides that inhibit soil microbiota.

Since sunflower has traditionally held a leading position among industrial oil crops in our country, all innovations concerning the crop cultivation technology (firstly, intensification) have been actively implemented by agricultural commodity producers over the past 20–30 years (Bazaliy et al., 2015; Butenko, 2003). However, the scientific community and some conscientious producers have expressed concern about excessive pesticide pressure on agrocenoses and the inefficient use of production inputs, especially the most expensive components: mineral fertilizers and plant protection products (Zhuykov et al., 2020; Lukhmenev, 2015; Thomas and Kravchuk, 1981).

The current trend toward partial or complete biologization of plant production technology has also become popular in sunflower cultivation. Recently, the issue of reducing the application of synthetic plant protection products and mineral fertilizers in sunflower raw material production both in scientific and production aspects has been a topic of discussion, scientific debates and production experiments (Bursela, 1995; Palamarchuk et al., 2012; Patika, 2001; Gritsev, 2015). However, analysis of the modern scientific journals allows the conclusion that, in most cases, their authors study certain factors of biologization of the crop production only fragmentarily (almost exclusively the application of mono- and poly-functional plant growth regulators, immunomodulators, and antistressants) (Sendetsky, 2017; Tarariko and Lychuk, 2014; Tkalenko, 2015).

The application of non-synthetic fungicides and insecticides in sunflower cultivation, despite its limited popularity as a protection measure, has not been thoroughly examined in the modern scientific literature, though it is more common in crop production practice (Bazaliy et al., 2019; Vavrinevich et al., 2013; Roberts, 1981). The current interest in microbial fertilizers as a means to increase the efficiency of plant uptake of macro- and meso-elements of mineral nutrition has also extended to sunflower cultivation technology. The use of chelate complexes in mineral nutrition systems has become a focus of scientific research among Ukrainian and foreign researchers (Bulygin et al., 2007; Buryak et al., 2014).

As interest in organic products on the domestic and foreign markets has risen, sunflower seeds and processed products (oil and oil cake) with organic status have become the most expensive lots. However, comprehensive domestic organic technology for the crop cultivation has not yet been developed due to unresolved issues with weed control (Ryazanov and Shevchuk, 2018; Tsikov and Matyukha, 2006; Malidža et al., 2000).

Ultimately, the analysis of the current state of research by scientists indicates an almost complete lack of reliable information regarding the comprehensive application of various methods of alternative protection of sunflower against a complex of harmful organisms within a unified system, the priority of certain groups (fungicidal and insecticidal protection), the complete rejection of synthetic pesticides and mineral fertilizers, and the cultivation of the crop based on organic technology (Ponomarenko et al., 2017; Tsandur et al., 2014).

Phytophage control in the research focused on the most harmful groups: wireworms (larvae of the species *Agriotes obscurus* and *Agriotes lineatus*), thrips (larvae of the species *Thrips tabaci*) and owlet moths (larvae of the species *Helicoverpa armigera* and *Agrotis segetum*) (Table 3).

Table 3. Registration of the most harmful phytophages in sunflower crops depending on the level of biologization of cultivation technology (average for 2018–2021).

Hybrid (factor A)	Cultivation technology (factor B)	Phytophages		
		Wireworm species (damaged seeds per linear meter)	Tobacco thrips (individuals per plant)	Owlet moth species (individuals per plant)
PR64F66 F1	Traditional	0.22	1.12	0.27
	Biologized I	0.18	1.07	0.20
	Biologized II	0.37	1.16	0.46
	Organic	0.31	1.15	0.42
	Extensive	0.84	2.33	2.64
Tunca F1	Traditional	0.19	1.15	0.22
	Biologized I	0.20	1.11	0.17
	Biologized II	0.29	1.09	0.50
	Organic	0.27	1.17	0.41
	Extensive	0.90	2.80	2.97
LSD_{05}	For average (main) effects	Factor A – 0.07; Factor B – 0.04	Factor A – 0.04; Factor B – 0.08	Factor A – 0.07; Factor B – 0.11
	For partial differences	Factor A – 0.12; Factor B – 0.10	Factor A – 0.08; Factor B – 0.10	Factor A – 0.05; Factor B – 0.04

The experiment demonstrates that replacing synthetic insecticides with organic preparations can provide comparable efficacy against key sunflower pests. Other researchers support this view. For instance, a trial conducted in Serbia using the product ATTRACAP® (Metarhizium brunneum CB15) compared to synthetic insecticides (Buteo Start 480 FS, Lumiposa, Force 20 CS, and Force 1.5 G) showed that the biological preparation ATTRACAP® achieved efficacy comparable to synthetic insecticides at low pest density. Moreover, the use of the biopreparation helped reduce the environmental impact (Gvozdenac et al., 2022).

The experiment revealed that, based on the index of the plant damage caused by wireworm larvae, the experiment variants in which the synthetic insecticidal seed protectant was replaced with an organic preparation were not inferior to either the control variant or the variant using biologized I technology, which also used a chemical preparation. The extensive technology variant of the crop cultivation, in which no insecticidal protectant was applied, was considerably inferior to the above variants, with seed damage from pests observed on 8.4–9.0 seeds per 10 linear meters of a row, representing 22–25% of the population.

A similar tendency was observed when analyzing the damage to sunflower plants caused by tobacco thrips larvae, which are agents of viral diseases. Both variants of biologized cultivation technology and organic technology were not inferior to traditional (intensive) technology, but extensive cultivation technology was considerably based on the indexes of plant damage caused by the pest larvae: there were 2.3–2.8 larvae per each plant.

The most dangerous pests for the generative part of sunflower yield – cotton and winter owlet moth larvae – were most harmful in the variant where neither synthetic nor organic insecticidal preparations were applied. On the plots, where extensive crop cultivation technology was implemented, each capitulum contained 2.6–2.9 larvae, which inevitably affected the crop hybrid yields. Maximal control of this pest was achieved with traditional intensive cultivation technology (the average index equaled 0.22–0.27 pieces per plant) and biologized I technology, where synthetic insecticidal preparations were also applied (0.17–0.20 pieces per plant, respectively). The technology variants using organic insecticides (biologized II and organic) were somewhat less effective in controlling owlet moth larvae: the average number of pests equaled 0.46–0.50 and 0.41–0.42 pieces per plant, respectively. This can be explained by the residual systemic effect of organic insecticidal preparations, which is less specialized compared to synthetic insecticides.

Research on the intensive use of biological control has shown that regions within the Brazilian agricultural sector that actively employ biological protection methods achieved a higher technical efficiency score of 0.863, compared to 0.823 in regions using traditional methods (Rodrigues et al., 2023).

During the research, we observed both epiphytotic and sporadic manifestations of the following fungal diseases in sunflower agrocenoses: phomosis (*Phoma helianthi*), phomopsis (*Phomopsis helianthi*), white rot (*Sclerotinia sclerotiorum*), grey rot (*Botrytis cinerea*), downy mildew (*Plasmopara halstedii*), septoriosis (*Septoria helianthi*), and brown rust (*Puccinia helianthi*). The extent of plant damage caused by these disease agents, depending on cultivation technology, is shown in Table 4.

Research confirms that organic and biologized technologies can be effective in controlling sunflower diseases, proving not inferior to conventional methods. However, their success depends on an integrated approach, including crop rotation, the selection of resistant hybrids, and careful monitoring. Extensive technology (without the application of protective agents) leads to significant pathogen buildup and yield loss (Tsikov and Matyukha, 2006; Tsandur et al., 2014; Zhuykov et al., 2024b; Siviter et al., 2023).

Table 4. Sunflower plant damage caused by the agents of fungal diseases depending on the level of biologization of cultivation technology (average for 2018–2021).

Hybrid (factor A)	Cultivation technology (factor B)	Plant damage, points						
		Phomosis (*Phoma helianthi*)	Phomopsis (*Phomopsis helianthi*)	White rot (*Sclerotinia sclerotiorum*)	Grey rot (*Botrytis cinerea*)	Downy mildew (*Plasmopara halstedii*)	Septoriosis (*Septoria helianthi*)	Brown rust (*Puccinia helianthi*)
PR64F66 F1	Traditional	0.7	1.4	1.2	1.5	0.6	1.7	2.2
	Biologized I	0.5	1.5	1.1	1.7	0.4	1.9	2.1
	Biologized II	0.9	1.3	1.5	1.2	0.4	1.4	2.2
	Organic	0.7	1.0	1.2	1.2	0.4	1.6	2.0
	Extensive	2.3	2.7	3.1	2.4	0.8	3.3	3.5
Tunca F1	Traditional	0.9	1.0	1.2	1.0	0.4	2.0	2.0
	Biologized I	0.7	1.2	1.4	1.0	0.5	2.1	1.7
	Biologized II	1.2	1.0	1.5	1.5	0.4	1.9	2.5
	Organic	0.9	1.1	1.2	1.6	0.7	1.8	2.4
	Extensive	2.5	2.2	3.3	2.2	0.6	3.5	3.8
LSD_{05}	For average (main) effects	Factor A – 0.27; Factor B – 0.40						
	For partial differences	Factor A – 0.22; Factor B – 0.31						

Analysis of the above data shows that, in terms of fungicidal effectiveness, organic preparations used in the sunflower protection system under biologized II and organic technologies were not inferior to synthetic compounds used in biologized I and traditional intensive technologies. The crop cultivation using extensive technology (without application of fungicidal preparations) showed a considerably higher degree of plant damage by phytopathogens (mainly, by phomopsis, white and grey rot, septoriosis, and brown rust). The manifestation of the latter was 3.5–4.0 points in some years, which had a crucial impact on the crop productive characteristics. The issue of sunflower protection against pests and diseases by means of biological preparations is not as acute nowadays as it was 4–5 years ago. Agricultural producers have sufficient domestic and foreign organic insecticides and fungicides. However, under current conditions, weed control in the agrocenosis of the crop cultivated using organic technology is possible only through agrotechnical measures – mainly mechanical soil tillage with harrows and rotary roes.

According to the results of our research, these methods of mechanical weed control in sunflower crops proved to be highly efficient and, when implemented timely and properly, were not inferior in their effect on major weeds to chemical protection measures taken in the variants of traditional intensive and biologized I technologies (Table 5).

Table 5. Dynamics of weediness in sunflower hybrid crops depending on the level of biologization of cultivation technology (average for 2018–2021).

Hybrid (factor A)	Cultivation technology (factor B)	Development stage					
		First set of true leaves		Formation of a capitulum		Seed maturation	
		annual, pcs/m^2	perennial, pcs/m^2	annual, pcs/m^2	perennial, pcs/m^2	annual, pcs/m^2	perennial, pcs/m^2
PR64F66 F1	Traditional	0.3	0.4	4.2	2.9	7.4	5.1
	Biologized I	0.2	0.5	4.0	2.5	6.5	2.4
	Biologized II	0.6	0.5	1.9	1.0	1.7	0.9
	Organic	0.6	0.4	1.8	1.3	2.0	1.4
	Extensive	4.6	2.7	8.4	5.1	10.4	5.5
Tunca F1	Traditional	0.3	0.5	4.4	3.1	6.5	3.3
	Biologized I	0.3	0.3	4.4	3.0	7.2	3.2
	Biologized II	0.5	0.3	1.4	1.1	1.9	1.6
	Organic	0.3	0.7	1.7	0.9	2.1	1.3
	Extensive	4.1	2.2	8.8	4.4	9.3	4.0
LSD_{05}	For average (main) effects	Factor A – 0.16; Factor B – 0.34					
	For partial differences	Factor A – 0.11; Factor B – 0.19					

Our experience in using rotary hoes and harrows in the biologized sunflower weed control system shows that these operations should be performed only in that part of a day when the crop turgor is minimal and the plant is maximally resistant to mechanical damage (noon hours under high air temperature and solar insolation). The machine operating speed should not exceed 5–8 km/h, depending on the crop development stage.

At the initial stages of ontogenesis (before the first set of true leaves), there was no essential difference in weediness among sunflower hybrid crops under intensive (traditional), biologized, and organic cultivation technologies. The number of annual and perennial weeds on the plots treated with soil herbicide and on the plots where plant protection was achieved through pre- and post-emergence harrowing was 0.3–0.7 pcs/m^2, respectively. In contrast, at the initial stages, the variant with the extensive crop cultivation technology had more weeds in the crops, with the number of annual species at 4.1–4.6 pcs/m^2, and perennial species at 2.2–2.7 pcs/m^2. The phytotoxic impact of soil and post-emergent herbicides on weeds was observed in the traditional cultivation technology variant up to the stage of the 6th–7th sets of true leaves. Starting from the stage of capitulum formation, an increase in the number of harmful herbaceous species was recorded. The intensive cultivation technology and biologized I technology variants were inferior to the biologized II and organic cultivation technology variants in terms of the index of weediness, where harrowing was alternated with inter-row tillage with covering. At the stage of seed filling, when the habit of sunflower plants prevented inter-row tillage without damaging the plants, the index of weediness (mainly due to annual late species) began to increase, though not as sharply as in the variants where chemical herbicides were applied (intensive and biologized I technologies), and especially not as much as in the absence of weed control (extensive technology). Currently, scientists and agricultural producers have no clear viewpoint concerning the negative impact of synthetic pesticides (mainly insecticidal-acaricidal preparations) on the activity of insect pollinators in sunflower agrocenoses. As a typical entomophilous cross-pollinated crop, sunflower requires a certain number of entomofauna representatives capable of fully pollinating the female flowers in a capitulum. Honey bees (*Apis mellifera*) are the primary pollinators in this regard. Therefore, some researchers emphasize that elements of modern intensive technologies – particularly plant protection measures applied in the second half of crop development – negatively affect bee visitation during the flowering stage (Castor et al., 2025; Lavrenko et al., 2024; Siviter et al., 2024; Siviter et al., 2021). Others are convinced that the situation is not so serious, referring to modern achievements of agro-chemical companies in developing products that are relatively harmless to this species and do not have repellent characteristics (Siviter et al., 2023; Brown et al., 2016; Linguadoca et al., 2021; Siviter et al., 2018). Considering that disruption of sunflower entomophilous pollination can result in up to 40% of seeds missing from a capitulum and, consequently, yield losses of 20–25%, we conducted research on the intensity of honey bee visits to sunflower plants in the experimental variants. The results of our research indicate that the intensity of honey bee visits to flowering inflorescences of the crop was considerably higher in the variants where elements of biologization were applied to the insecticidal crop protection system (replacing synthetic insecticides with biological preparations) than in the variants where chemical plant protection products were used against entomophages (traditional intensive and biologized I cultivation technologies) (Figure 1).

On average, in biologized variants, there were 4.5 bees per crop inflorescence, while only 1.5 bees were observed on plants where bio-insecticides were not used, indicating a considerable repellent impact of the synthetic preparations applied. In addition, we observed a few dead honey bees in the variants of intensive and biologized sunflower cultivation technologies, suggesting not only repellent but also residual insecticidal effects of the modern insecticidal preparations on beneficial entomofauna. In the variant with extensive cultivation technology, bee visitation of inflorescences was less intense, which can be explained by slightly lower nectar secretion and earlier cessation of flowering in these plants.

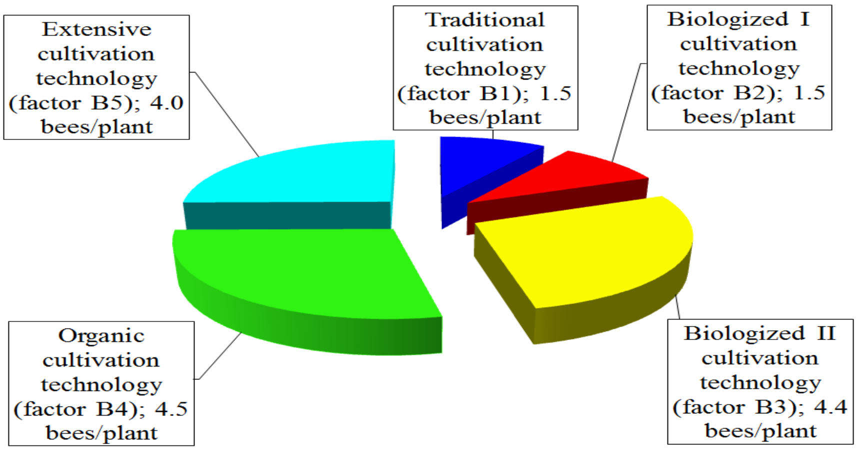

Figure 1. Intensity of honey bee visits to sunflower plants during the flowering stage, depending on cultivation technology (average for 2018–2021, bees per plant).

Conclusion

During the growing season, under conditions of intensive sunflower cultivation technology, the total colonization of the soil arable layer in the research plot and the amount of microflora in the main groups considerably decreased – by 6.1–40.9% in comparison with the variants where some elements of biologization or their complex application were implemented (organic cultivation technology).

The application of modern insecticidal preparations of organic origin in sunflower plant protection under biologized and organic cultivation technologies allows controlling a whole array of the most harmful phytophages and is not inferior to synthetic insecticides in effectiveness. The exception is the crop protection against owlet moth larvae, which, because of their biological and ecological characteristics, require an insecticidal preparation with more systemic properties that are generally not characteristic of organic preparations, with few exceptions. We observed no residual insecticidal or repellent impacts of biological preparations on major crop pollinators – honey bees as their attendance of flowering inflorescences was three times higher than in the variants of intensive and biologized I technologies.

Fungicide protection of sunflower plants, based on organic preparations, is as efficient and effective as protection systems based on synthetic fungicides: the hybrid damages caused by the most widespread phytopathogens did not differ depending on the type of preparations. Special control in sunflower agrocenosis under any cultivation technology is required for the agent of brown rust, which is inclined to secondary infestation because of climate conditions such as dry and windy weather.

Mechanical soil tillage as a method of the crop protection against weeds is an effective alternative to herbicide use. The application of pre- and post-emergence harrowing, rotary hoes, and inter-row tillage within the crop protection systems as a component of biologized and organic technologies for sunflower cultivation, is as effective as the use of soil and post-emergence synthetic herbicides. It is even more effective by the control of the second and third waves of late spring weed species in the second half of the plant development.

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MIKROBNA AKTIVNOST I FITOSANITARNI USLOVI U USEVU SUNCOKRETA U ZAVISNOSTI OD NIVOA BIOLOGIZACIJE TEHNOLOGIJE GAJENJA

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R e z i m e

Istraživanje je sprovedeno u periodu od 2018.-2021. godine. Poljski ogledi su sprovedeni u četiri ponavljanja primenom metode dizajna sa podeljenim parcelama (engl. *split-plot design method*). U studiji su ocenjivani sledeći elementi tehnologije gajenja: A – hibrid suncokreta: A1 – PR64F66 F_1; A2 – Tunca F_1; B – tehnologija gajenja: B1 (tradicionalna); B2 (biologizovana I); B3 (biologizovana II); B4 (organska); B5 (ekstenzivna). Istraživanje je pokazalo da je tokom vegetacionog perioda, pri primeni intenzivne tehnologije gajenja suncokreta, došlo do značajnog smanjenja kako ukupne kolonizacije obradivog sloja zemljišta na oglednoj parceli, tako i količine mikroflore od strane određenih najvažnijih grupa, u poređenju sa varijantama u kojima su primenjeni neki elementi biologizacije ili njihova kompleksna primena (organska tehnologija gajenja) za 6,1–40,9%. Primena savremenih insekticida organskog porekla u zaštiti suncokreta, pri biologizovanoj i organskoj tehnologiji gajenja, omogućava suzbijanje čitavog niza najštetnijih fitofaga i po efikasnosti nije inferiorna u odnosu na sintetičke insekticide. Izuzetak predstavlja zaštita useva od larvi sovice, koje, zbog svojih bioloških i ekoloških osobina, zahtevaju insekticid sa izraženijim sistemskim svojstvima, koja nisu karakteristična za organske preparate, uz nekoliko izuzetaka. Biološki preparati nisu imali rezidualni insekticidni ili repelentni efekat na glavne oprašivače useva. Obrada drljačama i rotacionim motičicama pre i posle nicanja, kao i međuredna obrada u sistemu zaštite useva od korova, kao komponenta biologizovane i organske tehnologije gajenja suncokreta, jednako je efikasna kao primena zemljišnih insekticida i sintetičkih herbicida posle nicanja.

Ključne reči: suncokret, hibrid, biologizacija, mikroorganizmi, bolesti.

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