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Features of Forming Soil Regimes under Sunflower Cultivation with Different Levels of Biologization in Non-irrigated Conditions of the Southern Steppe of Ukraine

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ABSTRACT

Reducing pressure on agrolandscapes while maintaining indicators of economic efficiency is a promising and relevant task for researchers. The article presents the results of a four-year study on the formation of water, nutrient, and microbial regimes in the soil of mid-early ecological group hybrid sunflower crops PR64F66 F1 and Tunca F1 at different levels of biologization of zonal variety cultivation technologies in the conditions of the Southern Steppe of Ukraine: traditional intensive, extensive minimal, organic, and two levels of biologized. The dependence of the reduction in average daily soil moisture consumption on the application of biologization elements was established. The minimum value of the water consumption coefficient over the years of the study was found for organic cultivation technology – 407 (PR64F66 F1) and 423 (Tunca F1) m^3/ton of dry matter, while the least economical consumption of active moisture for biomass formation was recorded for the extensive cultivation technology variant – 523 and 624 m^3/ton respectively. Variants with the application of biologization elements in the mineral nutrition system were characterized by significantly higher efficiency and economy of nitrogen consumption from soil reserves. Throughout the vegetation period, under the conditions of intensive sunflower cultivation technology, both the overall population of the plowed soil layer and the number of microflora for individual key groups decreased significantly compared to variants where individual elements of biologization or their complex application (organic cultivation technology) were implemented, by 6.1–40.9%.

Keywords: sunflower, hybrids of the mid-ripening group, biologization levels, organic growing technology, water consumption, removal of mineral nutrition elements, soil microbiological activity.

INTRODUCTION

A characteristic feature of modern agrophytocenoses in all agricultural zones of Ukraine is the increasing expansion of marginal crops, where agricultural producers prioritize economic indicators of farming, while ecological aspects are either not taken into account or considered residual (Honcharova and Kirichenko 2021). In this sense, the situation with sunflower production in the country has long moved from being a concern for experts to becoming a nationwide problem (Yeremenko and Onyschenko 2021; Chekhova 2022). Therefore, its solution (reducing pressure on agrolandscapes while maintaining indicators of economic efficiency) is a promising and relevant task for researchers (Kovalenko et al., 2021; Petrychenko et al., 2022). Taking into account the above, the process of biologization of sunflower production or the conversion of a certain portion of its sown areas to "organic tracks" is seen today as almost the only way to resolve the "stalemate" situation that has arisen in the domestic market of agricultural products (Ostapenko et al., 2020; Sokolovska and Maschenko 2023).

It should be noted that this problem is not indifferent to the global and domestic scientific community. A significant number of scientific research and publications have recently been dedicated to the issue of biologization of sunflower production (Adeleke and Babalola 2020; Baghbani-Arani et al., 2020; Mouillon et al., 2020). A particular trend is that researchers increasingly attempt to solve the problem comprehensively, taking into account not only unfavorable biotic factors of agrocenosis (pests, phytopathogens, weeds) but also abiotic factors, primarily hydrothermal ones (Chabert et al., 2020; Lachabrouilli et al., 2021; Soothar et al., 2021). This trend is also clearly observed during the analysis of presentations of new products from plant protection companies, which increasingly include preparations of organic origin that not only serve purely pesticidal functions but also possess properties of immunomodulators, thermoprotectors, growth regulators, cytokinins, etc. (Chen et al., 2021; Chuiko 2021). Using modern biologically active substances of natural origin in production conditions makes it possible not only to increase the productivity per hectare of sunflower sowing but also to significantly influence the quality indicators of the harvest.

As evidenced by the results of recent scientific developments and the practice of their industrial implementation, today there is a real opportunity to reduce the area of sunflower plantations without reducing gross seed yields (Zahra et al., 2020; Shakalii et al., 2022). An analysis of scientific periodicals on the mentioned problem indicates that the majority of researchers prefer a fragmented study of individual elements of biologization of sunflower cultivation technology: the use of biofungicides (Flore et al., 2023), organic fertilizers (De Jesus et al., 2020), minimization or complete abandonment of certain types of mineral supplements, reduction of their doses and norms, revision of application methods (Chappa et al., 2023; Sydiakina and Ivaniv 2023), and the inclusion of biologically active substances of organic origin in cultivation technology (Uwineza and Waśkiewicz 2020). Some researchers adhere to a different concept: they declare a scientifically substantiated saturation of agrophytocenoses with sunflower without fundamentally revising the zonal cultivation technology to include elements of biologization (Dehtiarova 2023). The inclusion of elements aimed at optimizing plant life factors in sunflower cultivation technology (and elements of biologization are not an exception in this aspect) aims to transform the basic ecological factors that determine the final seed productivity indicator (Polyakov and Shcherbak 2022; Silva et al., 2023). In the conditions of the Southern Steppe of Ukraine, the water, nutrient, and microbiological regimes of the soil are of crucial importance for sunflower cultivation. Our research is precisely aimed at studying this issue.

RESEARCH METHODOLOGY

The aim of the scientific research is to determine changes in the water, nutrient, and microbial regimes of the soil under the cultivation of mid-early sunflower hybrids depending on the cultivation technology. The research was conducted from 2020 to 2023 on the southern chernozem of the State Enterprise Experimental Farm "Pioneer" of Beryslav District, Kherson Region. The research is two-factor. Factor A – mid-early sunflower hybrids: PR64F66 F1 (Pioneer) and Tunca F1 (Limagrain). Factor B – cultivation technologies:

- traditional (intensive) technology – recommended for the conditions of the Southern Steppe of Ukraine, using mineral fertilizers and chemical plant protection agents;
- biologized I – intensive technology, in which mineral fertilizers were replaced with organic ones (multi-functional preparation TM "Eco-Growth");
- biologized II – intensive technology, in which chemical fungicides and insecticides were replaced with biological preparations, and herbicides – with mechanical weed control operations. For fungicidal protection, preparations TM "ENZIM-Agro" Gaubsin-FORTE and Viridin (Trichodermin) were used, for insecticidal protection – insect-acaricides TM "ENZIM-Agro" Entocid (Metarhizium) and Actarophyt;
- organic technology – a technology in which the care system for crops is based exclusively on the use of biological preparations (both fertilizers and pesticides);
- extensive (minimal) – cultivation technology, in which the care system for crops is represented only by mechanical weed control operations without the use of chemical and biological fertilizers and plant protection agents.

TM "Eco-Growth" – strains of *Bacillus thermophiles*, *Bacillus subtilis*, phosphorus-mobilizing, nitrifying bacteria, and chelated micronutrients (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 acid, 0.0055 g/l phytohormones, 0.049 g/l polysaccharides, vitamins, cytokinins, gibberellin compounds. Used for seed treatment at a rate of 2 l/t for pre-sowing treatment and 2 l/ha for foliar feeding of crops.Gaubsin-FORTE – biofungicide, two strains of *Pseudomonas aureofaciens* culture with a cell titer of not less than 4×10^9 CFU/ml. The application rate for vegetative plant spraying is 2 l/ha. Viridin (Trichodermin) – biofungicide, spores and mycelium of *Trichoderma spp.* fungi with a titer of not less than 1×10^8 CFU/ml and metabolites – biologically active substances. The application rate for seed treatment is 5 l/t for pre-sowing treatment and 2 l/ha for vegetative plant spraying. Entocid (Metarhizium) – bioinsecticide, spores of entomopathogenic fungi not less than 2×10^8 CFU/ml. Used for soil spraying for pre-sowing treatment at a rate of 5 l/ha. Actarophyt – bioinsecticide, a complex of natural avermectins produced by the beneficial soil fungus *Streptomyces avermitilis* (abamectin – 50%, emamectin – 50%). The total toxin content is not less than 1.8%. The application rate for plant spraying is 0.2 l/ha.The research was conducted using a split-plot design with partial randomization, with four replications.Sunflowers were grown in the study under natural moisture conditions. Groundwater on the farm site is located at a depth of 16 meters. Artesian well water with a mineralization level of 0.4 g/dm^3 was used for crop spraying. According to the classification of natural waters by mineralization, water from the artesian well is considered moderately fresh (0.1–0.6 g/dm^3). Soil moisture was determined by the thermogravimetric method, total water consumption – by the water balance method, the content of easily hydrolyzed nitrogen in the soil – according to Kornfield, the content of mobile phosphorus – according to Chirikov. The computer program "Agrostat" was used for statistical analyses of data.

RESEARCH RESULTS AND THEIR JUSTIFICATION

The study of the dynamics of the indicator, which is the basis for further formation of water consumption per unit area of crop cultivation and the overall inflow component of the water balance of the sunflower wedge – soil moisture in the 0–100 cm layer, provides grounds to state that from the moment of emergence to the BBCH 15 micro-stage (5 true leaves), it did not have a significant dependence on the factors of the study and changed synchronously across all variants of crop hybrids and levels of biologization of cultivation technology. Starting from the BBCH 15 micro-stage, a regularity was established, according to which the decrease in soil moisture indicator in the 0–100 cm layer occurred more intensively in the variants of traditional (intensive) and extensive (minimal) cultivation technologies in the crops of both sunflower hybrids. At the BBCH 55 micro-stage, no significant difference was found in the soil moisture indicator in the 0–100 cm layer for any of the factors. In the future, this difference became evident: the content of active moisture in the soil under plants in the variants of partial (biologized I and II) and complete biologization (organic) cultivation technology was significantly higher than in the variants of intensive and extensive cultivation technology. This difference became particularly significant in the final stages of observation – BBCH 75 and BBCH 89 micro-stages. Thus, at the BBCH 89 micro-stage, on average, according to factor A, the soil moisture in the 0–100 cm layer was: traditional (intensive) technology – 13.9%, biologized I – 14.3%, biologized II – 14.5%, organic – 14.8%, minimal extensive – 13.1% (Figure 1, 2).

However, drawing conclusions about the actual state of soil moisture based solely on its moisture content would be incorrect. The indicator of productive moisture reserves in the soil, which is the difference between total and "dead" reserves, also deserves attention. According to our research, the reserves of productive moisture in the 0–100 cm soil layer in the first half of the crop's vegetation period (up to the BBCH 55 micro-stage) did not have a significant dependence on either the sunflower hybrid or the cultivation technology implemented in a particular experiment variant. Starting from the BBCH 65 micro-stage, the dynamics of active moisture loss in the 0–100 cm soil layer was more intensive in the control (traditional technology) and in the variants using extensive (minimal) cultivation technology. Cultivation technologies incorporating elements of biologization were characterized by significantly lower intensity of moisture loss in the 0–100 cm soil layer. For example, at the BBCH 89 micro-stage, the average moisture reserves in the 0–100 cm layer in the biologized I variant were 250 m^3/ha, in the biologized II variant – 254 m^3/ha, and in the organic variant – 257 m^3/ha, compared to

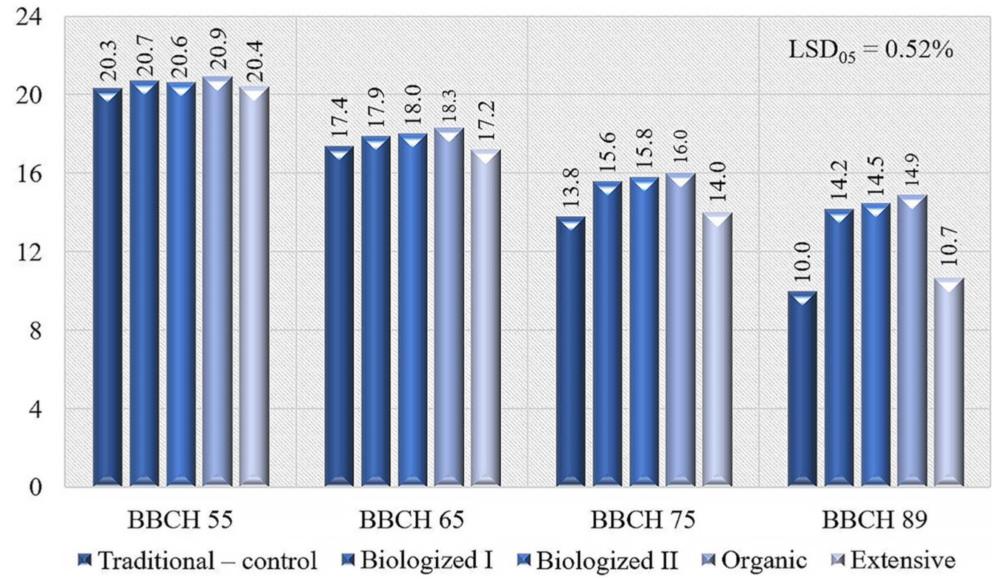

Figure 1. Dynamics of humidity in the soil layer 0–100 cm in the second half of the growing season of the Tunca F1 hybrid depending on the cultivation technology (average for 2020–2023), %

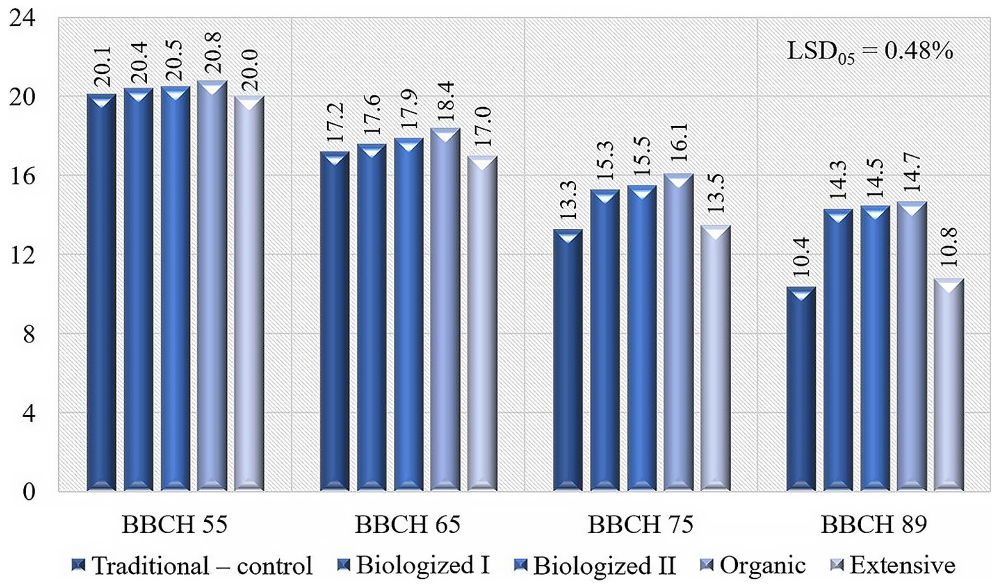

Figure 2. Dynamics of humidity in the soil layer 0–100 cm in the second half of the growing season of the PR64F66 F1 hybrid depending on the cultivation technology (average for 2020–2023), %

182 m^3/ha and 189 m^3/ha in the intensive and extensive cultivation technologies, respectively, on average according to factor A (Table 1).

Thanks to its powerful root system, sunflower is capable of absorbing moisture from a depth of up to 1.8–2.0 meters, so significant dehydration of the 0–100 cm soil layer was observed in the experiment. For example, in the intensive cultivation technology variant, the initial reserves of active moisture, formed during the emergence period (BBCH 10), were depleted by 86.2% by the BBCH 89 micro-stage. In the biologized I variant, it was depleted by 80.7%, in the biologized II variant – by 80.4%, in the organic variant – by 80.0%, and in the extensive variant – by 85.5%. However, a more objective indicator that allows for analyzing the efficiency of plant consumption of active soil moisture is its average daily consumption. Table 2 shows the results of calculating this indicator for the research variants.

The indicator of average daily consumption of soil moisture by sunflower plants is somewhat

Table 1. Dynamics of the content of productive moisture in the 0–100 cm soil layer under sunflower depending on the cultivation technology (average for 2020–2023), m^3/ha

Hybrid (factor A)	Cultivation technology (factor B)	Growth and development phase					
		BBCH 10	BBCH 12	BBCH 55	BBCH 65	BBCH 75	BBCH 89
PR64F66 F1	Traditional – control	1294	1243	1194	305	242	175
	Biologized I	1294	1245	1197	313	273	249
	Biologized II	1294	1245	1200	315	277	254
	Organic	1294	1247	1199	321	280	261
	Extensive	1294	1248	1190	301	245	187
Tunca F1	Traditional – control	1294	1241	1198	301	233	182
	Biologized I	1294	1244	1199	308	268	250
	Biologized II	1294	1246	1202	313	271	254
	Organic	1294	1247	1205	322	282	257
	Extensive	1294	1242	1190	298	236	189
LSD_{05}	For mean (main) effects	A – 30.7; B – 29.4					
	For partial differences	A – 12.2; B – 28.0					

Table 2. Average daily moisture consumption of sunflower plants according to the experiment options (average for 2020–2023)

Hybrid (factor A)	Cultivation technology (factor B)	Reserve of active moisture, m^3/ha		Total moisture consumptio, m^3/ha	Vegetation duration, days	Average daily consumptio, m^3/ha/day
		BBCH 10	BBCH 89			
PR64F66 F1	Traditional – control	1294 ± 12.2	175 ± 1.7	1119	111	10.1
	Biologized I	1294 ± 12.2	249 ± 2.1	1045	115	9.1
	Biologized II	1294 ± 12.2	254 ± 2.2	1040	118	8.8
	Organic	1294 ± 12.2	261 ± 2.3	1033	121	8.5
	Extensive	1294 ± 12.2	187 ± 1.8	1107	109	10.2
Tunca F1	Traditional – control	1294 ± 12.2	182 ± 1.8	1112	109	10.2
	Biologized I	1294 ± 12.2	250 ± 2.1	1044	114	9.2
	Biologized II	1294 ± 12.2	254 ± 2.2	1040	115	9.0
	Organic	1294 ± 12.2	257 ± 2.3	1037	119	8.7
	Extensive	1294 ± 12.2	189 ± 1.9	1096	108	10.1

conditional, as it does not take into account the moisture input from atmospheric precipitation. However, it is sufficient for identifying the general trend in the dependence of moisture consumption by the crop on the level of biologization of the cultivation technology.

If this indicator did not have a significant dependence on factor A, a dependence on the reduction of soil moisture consumption due to the application of biologization elements was established for factor B. In the intensive cultivation technology variant, 1 hectare of sowing consumed an average of 10.15 m^3 of water per day, while in the biologized I variant, this consumption decreased to 9.15 m^3, in the biologized II variant – to 8.90 m^3, and the most economical consumption was determined in the organic cultivation technology – 8.60 m^3/ha/day. The extensive cultivation technology variant did not differ from the control variant in terms of average daily water consumption, averaging 10.15 m^3/ha/day.

The criteria by which it is advisable to conduct the most objective comparison of research variants in terms of the efficiency of using the most limiting factor of the cultivation zone – active moisture, are, as known, the calculated indicators of total water consumption and water consumption coefficient. The latter allows analyzing the level of specific water consumption for the formation of one unit of dry biomass. According to the research results, the application of biologization elements in sunflower cultivation technology

Table 3. Components of the water balance of the 0–100 cm soil layer depending on the factors of the experiment (average for 2020–2023)

Hybrid (factor A)	Cultivation technology (factor B)	Soil moisture, m^3/ha	Precipitation moisture during the growing season, m^3/ha	Total water consumption, m^3/ha	Dry biomass yield, t/ha	Coefficient of water consumption, m^3/t
PR64F66 F1	Traditional – control	1119	2037	3156	6.04	523
	Biologized I	1045	2042	3087	7.34	421
	Biologized II	1040	2042	3082	7.27	424
	Organic	1033	2042	3075	7.56	407
	Extensive	1107	2037	3144	5.26	598
Tunca F1	Traditional – control	1112	2037	3149	5.89	534
	Biologized I	1044	2042	3086	7.11	434
	Biologized II	1040	2042	3082	7.03	438
	Organic	1037	2042	3079	7.28	423
	Extensive	1096	2037	3133	4.94	634

significantly influenced the water consumption coefficient of both hybrids. The minimum values of the water consumption coefficient on average for the years of research were established for organic cultivation technology – 407 (Tunca F1) and 423 (PR64F66 F1) m^3/ton of dry matter, and the least economical water consumption for biomass formation was determined for extensive cultivation technology – 523 and 624 m^3/ton respectively (Table 3). The water consumption coefficient indicator for sunflower crops on average for factor A is shown in Figure 3.

Compared to the control (traditional cultivation technology), the variant of biologized I technology, where synthetic mineral fertilizers were replaced with organic fertilizers, was characterized by 19.3% less water consumption for the formation of one unit of dry biomass, and the variant of biologized II technology (replacement of chemical pesticides with organic preparations for protection) – by 18.5% more economical water consumption. Organic technology (application of exclusively biological fertilizers and pesticides) proved to be more efficient in terms of water consumption by 21.5%, while extensive technology led to an increase in the water consumption coefficient by 16.5% compared to the control. A significant inhibiting factor hindering the more intensive implementation of biologization principles in modern agriculture is a certain "psychological barrier" for

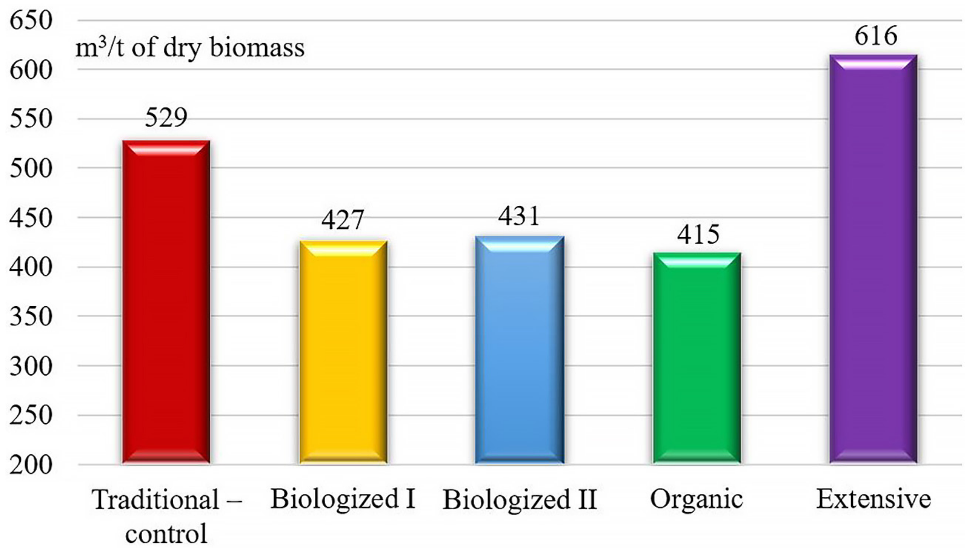

Figure 3. Sunflower water consumption rate depending on cultivation technology (average for 2020–2023), m^3/t of dry biomass

most agricultural producers regarding the refusal to use a certain amount of mineral supplements in the crop's mineral nutrition system and their replacement with biological (organic) fertilizers (Łuczka and Kalinowski 2020; Jiang et al., 2022).

At the same time, scientists have proven that the application of biologized methods in building the sunflower nutrition system by incorporating microbiological fertilizers into its cultivation technology, which are capable of converting immobilized and hard-to-access forms of macroelements from soil reserves into a highly labile state, chelated complex microfertilizers containing a full range of meso- and microelements together with macroelements and characterized by cumulative action and almost 100% assimilation, allows for a fundamental reconsideration of the principles of building the mineral nutrition system (Sydiakina and Pavlenko 2021; Alzamel et al., 2022). Modern biologized technologies for sunflower cultivation are based on a significant (up to 50–60%) transition of the crop's nutrient system from mineral fertilizers, which are characterized by high levels of inert substances, insufficient absorption by the plant's root system, significant losses of active substances before being absorbed by the soil absorption complex, etc., to biological multifunctional fertilizers (Domaratskiy et al., 2020; Domaratskyi, 2021; Sydiakina and Hamajunova 2023).

Regarding the complete (100% of the norm) abandonment of mineral fertilizers in the crop's cultivation technology in favor of exclusively organic fertilizers, biopreparations, chelated microcomplexes, there are currently no scientifically proven positive results of such technological solutions in the scientific literature. Therefore, an important task of our research was to analyze changes in the nutrient regime of the plow layer of soil under different scenarios of using both mineral and biological fertilizers and their interaction with complex multifunctional preparations. The determination of the content of readily hydrolyzable nitrogen showed that the level of provision with this element is relatively low (Table 4).

It has been established that the dynamic process of changing the content of available nitrogen in the soil has significant peculiarities, namely: in the variant of traditional and biologized II technologies, where the full rate of mineral fertilizers was applied, the nitrogen content in the soil significantly decreased throughout the entire vegetation period until the micro-stage BBCH 89. A similar pattern was observed for extensive (minimal) cultivation technology. Different results were obtained for the use of biologized I and organic cultivation technologies: starting from the emergence phase to the micro-stage BBCH 55, there was a slight increase in the content of readily hydrolyzable nitrogen in the plow layer of soil, which can be explained by the intensification of nitrifying activity of both natural soil microflora and bacterial strains included in microbiological preparations. From the micro-stage BBCH 65 to BBCH 89, the content of readily hydrolyzable nitrogen in the 0–30 cm soil layer decreased. The intensity of loss of available nitrogen in the plow layer of soil during the crop vegetation period averaged for factor A was as follows: in the

Table 4. Dynamics of the content of easily hydrolyzed nitrogen in the arable layer of the soil of the experimental site (average for 2020–2023), mg/100 g of soil

Hybrid (factor A)	Cultivation technology (factor B)	Growth and development phase					
		BBCH 10	BBCH 12	BBCH 55	BBCH 65	BBCH 75	BBCH 89
PR64F66 F1	Traditional – control	3.91	3.65	3.22	2.62	2.04	1.56
	Biologized I	1.94	2.27	2.97	2.17	1.88	1.22
	Biologized II	3.83	3.53	3.17	2.90	2.23	1.71
	Organic	1.82	2.33	3.11	2.56	2.01	1.32
	Extensive	1.42	1.24	1.20	1.19	0.90	0.63
Tunca F1	Traditional – control	4.07	3.49	3.22	2.70	2.16	1.60
	Biologized I	1.94	2.22	2.91	2.24	1.81	1.27
	Biologized II	3.98	3.39	3.17	2.95	2.34	1.90
	Organic	1.82	2.19	3.30	2.64	2.10	1.29
	Extensive	1.60	1.44	1.40	1.31	1.04	0.77
LSD_{05}	For mean (main) effects	A – 0.14; B – 0.31					
	For partial differences	A – 0.08; B – 0.18					

traditional (intensive) technology variant – from 3.99 to 1.58 mg/100 g (utilized 60.4%), in the biologized I variant – from 1.94 to 1.25 mg/100 g (36.6%), in the biologized II variant – from 3.91 to 1.81 mg/100 g (53.7%), in the organic variant – from 1.82 to 1.31 mg/100 g (28.0%), in the extensive variant – from 1.51 to 0.70 mg/100 g (53.7%). Thus, variants with the application of elements of biologization in the system of mineral nutrition were characterized by significantly higher efficiency and economy of consumption of soil reserves of the main macroelement for potential yield formation.

The study of phosphorus content dynamics in the soil allows us to assert the absolutely similar nature of the dependence of this indicator on the investigated factors. Thus, in the variants of intensive, biologized II, and extensive technologies, the P_2O_5 content in the soil decreased throughout the vegetation period, with the only difference being that until the flowering phase, the intensity of this process was insignificant, and with the beginning of generative yield formation (from microstage BBCH 65 to BBCH 89), the intensity of phosphorus consumption by plants from the plow layer of soil significantly increased.

Regarding the efficiency of plant consumption of soil reserves of P_2O_5 during the vegetation period, averaged for factor A over the years of research, it amounted to: traditional (intensive) technology – from 7.63 to 5.71 mg/100 g (utilized 25.2%), biologized I – from 6.29 to 5.57 mg/100 g (14.5%), biologized II – from 7.67 to 5.44 mg/100 g (29.1%), organic – from 6.20 to 5.30 mg/100 g (14.7%), extensive – from 7.62 to 6.11 mg/100 g (19.8%). Thus, as in the case of available nitrogen, the biologization of the crop's mineral nutrition system led to an increase in the efficiency and rationality of consumption of mobile phosphorus (Table 5).

Considering the fact that the content of mobile potassium K_2O in the soil of the experimental plot is characterized as high (36.7 mg/100 g), and the calculated norm of mineral fertilizers applied in the variants of traditional (intensive) and biologized II cultivation technologies did not include the application of potassium component, we did not conduct an analysis of the dynamics of exchangeable potassium content in the soil and its consumption by sunflower plants. As for the dynamics of soil reserves of NO_3 and P_2O_5, the use of elements of biologization in the system of mineral nutrition in sunflower cultivation technology was determined by us as an effective method of increasing plant consumption of these macroelements from the soil.

In modern scientific works, the inhibitory effect of active substances and metabolites of synthetic pesticides (primarily fungicides and bactericides) on the total population and activity of soil microbiota has been repeatedly reported (Meena et al., 2020; Roman et al., 2021). In most cases, modern groups of pesticides are not selective in their action on pathogenic and beneficial microflora, therefore, along with controlling the population of crop pathogens, there is a significant potential danger of bactericidal action towards groups of microorganisms that play a direct role

Table 5. Dynamics of the content of available phosphorus in the arable layer of the soil of the experimental site (average for 2020–2023), mg/100 g of soil

Hybrid (factor A)	Cultivation technology (factor B)	Growth and development phase					
		BBCH 10	BBCH 12	BBCH 55	BBCH 65	BBCH 75	BBCH 89
PR64F66 F1	Traditional – control	7.63	7.34	6.48	6.06	5.77	5.70
	Biologized I	6.29	6.33	6.60	6.19	5.65	5.53
	Biologized II	7.67	7.25	6.49	6.21	5.73	5.43
	Organic	6.20	6.44	6.64	6.09	5.69	5.30
	Extensive	7.62	7.37	6.85	6.61	6.40	6.09
Tunca F1	Traditional – control	7.63	7.39	6.55	6.10	5.80	5.72
	Biologized I	6.29	6.38	6.62	6.17	5.66	5.60
	Biologized II	7.67	7.26	6.57	6.26	5.79	5.45
	Organic	6.20	6.50	6.68	6.15	5.73	5.29
	Extensive	7.62	7.41	6.87	6.72	6.50	6.12
LSD_{05}	For mean (main) effects	A – 0.07; B – 0.06					
	For partial differences	A – 0.02; B – 0.05					

Table 6. Dynamics of microbiological activity of 1 g of completely dry soil under different sunflower growing technologies (average for 2020–2023)

Cultivation technology (factor B)	Growth and development phase													
	BBCH 12							BBCH 89						
	Aerobic species, million	Ammonifying agents, million	Oligonitrophils million	Actinomycetes million	Nitrophils million	Cellulolytic, thousand	Nitrifying, thousand	Aerobic species million	Ammonifying agents million	Oligonitrophils million	Actinomycetes million	Nitrophils million	Cellulolytic thousand	Nitrifying, thousand
Traditional – control	17.5	16.6	12.9	1.0	15.1	1.3	7.1	10.3	11.3	8.9	0.7	9.7	0.7	5.1
Biologized I	18.9	17.0	16.2	1.1	15.0	1.3	8.3	20.6	23.0	19.0	0.9	18.4	2.2	10.9
Biologized II	19.5	17.2	16.9	1.0	15.6	1.7	8.5	20.9	23.3	19.4	0.8	19.0	2.3	11.6
Organic	19.6	17.6	17.2	1.1	15.4	1.8	8.6	21.3	23.7	19.3	0.9	19.2	2.5	12.1
Extensive	18.0	16.9	12.5	1.1	13.0	1.1	7.5	11.9	14.2	10.7	0.6	11.8	0.8	5.9

in soil formation processes, perform mineralization, nitrogen fixation, ammonification, cellulolytic functions, and act as antagonists to pathogenic microbiota (Shahid and Khan 2022).

In the case of sunflower production intensification, the activity of the aforementioned negative processes potentially increases by an order of magnitude, taking into account the premature return of sunflower to the same field in crop rotation, cases of repeated plantings, and even monoculture in individual and small-scale farming. This increase in pesticide load per hectare of sunflower wedge creates even more unfavorable conditions for the normal functioning of microorganisms in the plow layer of soil.

Below we present the results of experimental studies on the dynamics of soil microbiological activity under different sunflower cultivation technologies, focusing on the main groups of microorganisms involved in soil formation processes and responsible for various aspects of soil fertility formation. The experimental data indicate that during the vegetation period, under traditional (intensive) sunflower cultivation technology, both the overall colonization of the plow layer of soil on the experimental plot and the quantity of microflora by individual groups significantly decreased compared to variants where individual elements of biologization or their complex application were implemented (organic cultivation technology) (Table 6).

Thanks to the absence of negative pesticide pressure on the agroecosystem and the additional influx of soil microorganisms by specific groups, we observed a positive trend in the population dynamics of microorganisms in the variants of biologized I and II, as well as organic sunflower cultivation technologies. On average, based on factor A, from micro-stage BBCH 12 to micro-stage BBCH 89, the overall colonization of 1 g of completely dry soil by aerobic species increased as follows: in biologized I technology – by 8.3%, biologized II – by 6.7%, organic – by 8.0%; by ammonifying species – respectively by 6.1%, 6.2%, and 5.7%; oligonitrophils – by 14.7%, 12.9%, and 10.9%; nitrophils – by 18.5%, 17.9%, and 19.2%; cellulolytic – by 40.9%, 28.0%, and 28.0%; nitrifying – by 23.9%, 26.7%, and 28.9%.

A decrease in soil colonization was observed for the group of actinomycetes during the vegetation period in the variants of biologized and intensive technologies, which we interpret as a positive effect, as this group is mostly represented by pathogenic species that cause diseases in crops, including sunflowers. The analysis of soil microbiological activity dynamics in the variants of traditional and extensive cultivation technologies allows us to conclude that the number of soil microorganisms decreased in all groups, except for actinomycetes, with a higher intensity of this process observed in the traditional cultivation technology due to the use of synthetic pesticides that have an inhibitory effect on soil microbiota.

CONCLUSIONS

The technology of sunflower cultivation up to micro-stage BBCH 15 did not have a significant impact on the moisture content of the 0–100 cm soil layer. However, a decrease in this indicator was observed during the period from micro-stage BBCH 15 to BBCH 55, especially in the variants of traditional and extensive technologies. Starting from micro-stage BBCH 55, significant differences between the cultivation technology variants were observed, reaching their maximum during micro-stage BBCH 89. The biologized and organic sunflower cultivation technologies showed significantly higher moisture levels in the 0–100 cm soil layer. A similar pattern was observed for the indicator of productive moisture reserves in the 0–100 cm soil layer.The implementation of biologization elements in the cultivation technology contributed to a reduction in the daily water consumption by sunflower plants. The most efficient water consumption and minimal water consumption coefficient were observed when using organic agrotechnology.The content of easily hydrolyzable nitrogen in the plowed soil layer gradually decreased throughout the entire vegetation period for the traditional, extensive, and biologized II cultivation technologies. For the biologized I and organic technologies, a slight increase in this indicator was observed up to microstage BBCH 55, after which it started to decrease. Variants with the implementation of biologization elements in the mineral nutrition system showed more efficient consumption of easily hydrolyzable nitrogen and mobile phosphorus.

The overall colonization of the plowed soil layer and the quantity of microbiota by individual groups decreased more significantly during the vegetation period of sunflower in the traditional technology compared to variants where specific elements of biologization or their complex application were implemented (organic cultivation technology).

REFERENCES

1. Adeleke B.S., Babalola O.O. 2020. Oilseed crop sunflower (Helianthus annuus) as a source of food: Nutritional and health benefits. Food Science & Nutrition, 8(9), 4666–4684. https://doi.org/10.1002/fsn3.1783
2. Alzamel N.M., Taha E.M., Bakr A.A., Loutfy N. 2022. Effect of organic and inorganic fertilizers on soil properties, growth yield, and physiochemical properties of sunflower seeds and oils. Sustainability, 14(19), 12928. https://doi.org/10.3390/su141912928
3. Baghbani-Arani A., Jami M.G., Namdari A., Karami Borz-Abad R. 2020. Influence of irrigation regimes, zeolite, inorganic and organic manures on water use efficiency, soil fertility and yield of sunflower in a sandy soil. Communications in Soil Science and Plant Analysis, 51(6), 711–725. https://doi.org/10.1080/00103624.2020.1729791
4. Chabert S., Sénéchal C., Fougeroux A., Pousse J., Richard F., Nozières E., Geist O., Guillemard V., Leylavergne S., Malard C., Benoist A., Carré G., Caumes É., Cenier C., Treil A., Danflous S., Vaissière B.E. 2020. Effect of environmental conditions and genotype on nectar secretion in sunflower (*Helianthus annuus* L.). OCL, 27(51), https://doi.org/10.1051/ocl/2020040
5. Chappa L.R., Mugwe J., Gitari H.H., Maitra S. 2023. Upholding sunflower (Helianthus annuus) yield and profitability while maintaining soil fertility under intercropping with sunn hemp and mineral fertilizer application. http://dx.doi.org/10.30954/2347-9655.01.2023.4
6. Chekhova I. 2022. Sunflower is the main oil crop in Ukraine. Helia, 45(77), 167–174. https://doi.org/10.1515/helia-2022-0007
7. Chen L., Hu W.F., Long C., Wang D. 2021. Exogenous plant growth regulator alleviate the adverse effects of U and Cd stress in sunflower (*Helianthus annuus* L.) and improve the efficacy of U and Cd remediation. Chemosphere, 262, 127809. https://doi.org/10.1016/j.chemosphere.2020.127809
8. Chuiko D. 2021. Plant growth regulator effects on sunflower parents and F1 hybrids. Žemės ūkio mokslai, 28(2). https://doi.org/10.6001/zemesukiomokslai.v28i2.4508
9. De Jesus K.N., Menezes R.S.C., de Araujo Filho R.N., de Sa Barretto Sampaio E.V., Antonino A.C.D., Primo D.C. 2020. Maize and sunflower yields and soil changes after five years of organic fertilization in the semi-arid region of Paraiba, Brazil. Arid Land Research and Management, 34(4), 460–473. https://doi.org/10.1080/15324982.2020.1763515
10. Dehtiarova Z.O. 2023. Influence of short-term crop rotations with different proportions of sunflower on soil water regime. Land Reclamation and Water Management, 1, 94–101. https://doi.org/10.31073/mivg202301-349
11. Domaratskiy Y., Kaplina A., Kozlova O., Koval N., Dobrovolskyi A. 2020. Economic justification for the use of biological fungicides and plant growth stimulants for growing sunflower. Independent journal of management & production (IJM&P), 11(9), 2171–2184. https://doi.org/10.14807/ijmp.v11i9.1406
12. Domaratskyi Y. 2021. Leaf Area Formation and Photosynthetic Activity of Sunflower Plants Depending on Fertilizers and Growth Regulators. Journal of Ecological Engineering, 22(6). http://dx.doi.org/10.12911/22998993/137361
13. Flore M.P.T., Martial T.T.P., Ebenezer F.T., Aristide D., Annie E.C., Désire M.H., Thaddée B. 2023. Formulation of Biofungicides from Cymbopogon citratus and Tithonia diversifolia: Evaluating Its Antimicrobial Activities against Pythium myriotylum, the Causal Agent of Root Rot of Xanthosoma sagittifolium (L.) Schott. American Journal of Plant Sciences, 14(8), 896–914. https://doi.org/10.4236/ajps.2023.148060
14. Honcharova K., Kirichenko K. 2021. Assessment of the environmental component of sunflower production in agricultural enterprises. Green, Blue and Digital Economy Journal, 2(3), 7–12. https://doi.

org/10.30525/2661-5169/2021-3-2

15. Jiang Y., Li K., Chen S., Fu X., Feng S., Zhuang Z. 2022. A sustainable agricultural supply chain considering substituting organic manure for chemical fertilizer. Sustainable Production and Consumption, 29, 432–446. https://doi.org/10.1016/j.spc.2021.10.025
16. Kovalenko O., Gamajunova V., Neroda R., Smirnova I., Khonenko L. 2021. Advances in nutrition of sunflower on the southern steppe of Ukraine. Soils Under Stress. Springer, Cham, 215–223. https://doi.org/10.1007/978-3-030-68394-8_21
17. Lachabrouilli A.S., Rigal K., Corbineau F., Bailly C. 2021. Effects of agroclimatic conditions on sunflower seed dormancy at harvest. European Journal of Agronomy, 124, 126209. https://doi.org/10.1016/j.eja.2020.126209
18. Łuczka W., Kalinowski S. 2020. Barriers to the development of organic farming: A polish case study. Agriculture, 10(11), 536. https://doi.org/10.3390/agriculture10110536
19. Meena R.S., Kumar S., Datta R., Lal R., Vijayakumar V., Brtnicky M., Sharma M.P., Yadav G.S., Jhariya M.K., Jangir C.K., Pathan S.I., Dokulilova T., Pecina V., Marfo T.D. 2020. Impact of agrochemicals on soil microbiota and management: A review. Land, 9(2), 34. https://doi.org/10.3390/land9020034
20. Mouillon P., Caldwell B.A., Cordeau S., Pelzer C.J., Wayman S., Ryan M.R. 2020. Crop density affects weed suppression in organically managed Sunflower. Agronomy Journal, 112(1), 450–457. https://doi.org/10.1002/agj2.20059
21. Ostapenko R., Herasymenko Y., Nitsenko V., Koliadenko S., Balezentis T., Streimikiene D. 2020. Analysis of production and sales of organic products in Ukrainian agricultural enterprises. Sustainability, 12(8), 3416. https://doi.org/10.3390/su12083416
22. Petrychenko V., Petrychenko O., Fedoryshyna L., Kravchuk O., Korniichuk O., Nitsenko V. 2022. Agricultural Production in Ukraine: Ecological Challenges and Impact on the Quality of Life. Financial and credit activity problems of theory and practice, 4(45), 374–384. https://doi.org/10.55643/fcaptp.4.45.2022.3782
23. Polyakov O.I., Shcherbak A.D. 2022. Productivity of sunflower under the influence of mineral fertilizers and growth regulators. Scientific and Technical Bulletin of the Institute of Oilseed Crops NAAS, 33, 11–122. https://doi.org/10.36710/IOC-2022-33-11
24. Roman D.L., Voiculescu D.I., Filip M., Ostafe V., Isvoran A. 2021. Effects of triazole fungicides on soil microbiota and on the activities of enzymes found in soil: A review. Agriculture, 11(9), 893. https://doi.org/10.3390/agriculture11090893
25. Shahid M., Khan M.S. 2022. Ecotoxicological implications of residual pesticides to beneficial soil bacteria: A review. Pesticide Biochemistry and Physiology, 105272. https://doi.org/10.1016/j.pestbp.2022.105272
26. Shakalii S., Yurchenko S., Bahan A., Shevchenko V., Zaroza, A. 2022. Peculiarities of growth and development of sunflower depending on biopreparations. Bulletin of Poltava State Agrarian Academy, 3, 11–17. https://doi.org/10.31210/visnyk2022.03.01
27. Silva W.V.D., Taveira J.H.D.S., Fernandes P.B., Silva P.C., da Costa A.B., Costa C.M., Giongo P.R., Corioletti N.S.D., Gurgel A.L. 2023. Organic and mineral fertilization determining the agronomic performance of sunflower cultivars and soil chemical attributes. Revista Brasileira de Engenharia Agrícola e Ambiental, 27, 927–933. https://doi.org/10.1590/1807-1929/agriambi.v27n12p927-933
28. Sokolovska I., Maschenko Y. 2023. Biotechnological methods of growing sunflower in different fertilizer systems. Helia, 46(79), 233–243. https://doi.org/10.1515/helia-2023-0011
29. Soothar R.K., Singha A., Soomro S.A., Chachar A.U.D., Kalhoro F., Rahaman M.A. 2021. Effect of different soil moisture regimes on plant growth and water use efficiency of Sunflower: experimental study and modeling. Bulletin of the National Research Centre, 45, 121. https://doi.org/10.1186/s42269-021-00580-4
30. Sydiakina O., Ivaniv M. 2023. Sunflower hybrids productivity depending on the rates of mineral fertilizers in the south of Ukraine. Helia, 46(79), 245–259. https://doi.org/10.1515/helia-2023-0010
31. Sydiakina O.V., Hamajunova V.V. 2023. Current state and prospects of sunflower seed production. Taurian Scientific Bulletin, 118, 196–204. https://doi.org/10.32782/2226-0099.2023.131.25
32. Sydiakina O.V., Pavlenko S.H. 2021. Efficiency of application of microelements in the nutritional system of sunflower plants. Taurian Scientific Bulletin, 118, 152–158. https://doi.org/10.32851/2226-0099.2021.118.19
33. Uwineza P.A., Waśkiewicz A. 2020. Recent advances in supercritical fluid extraction of natural bioactive compounds from natural plant materials. Molecules, 25(17), 3847. https://doi.org/10.3390/molecules25173847
34. Yeremenko O., Onyschenko O. 2021. Economic effeciency of intensive technology of sunflower cultivation in the conditions of the southern steppe of Ukraine. Ştiinţa Agricolă, (2), 113–118. https://doi.org/10.5281/zenodo.5874241
35. Zahra T., Hamedi J., Mahdigholi K. 2020. Endophytic actinobacteria of a halophytic desert plant Pteropyrum olivieri: promising growth enhancers of sunflower. 3 Biotech, 10, 514. https://doi.org/10.1007/s13205-020-02507-8