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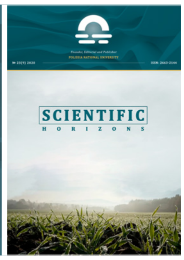

Efficiency of adjuvants use in the application of pre-emergence herbicides on annual sunflower crops

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Abstract. The use of adjuvants in chemical crop protection systems against harmful objects, including weeds, is one of the most substantial innovations in agricultural production. The study aimed to investigate the effectiveness of different rates of Peritera adjuvant in the system of pre-emergence herbicide protection of annual sunflower (*Helianthus annuus* L.) in the western forest-steppe. Research methods: field, laboratory, quantitative, mathematical and statistical to assess the reliability of the data obtained. Many years of research have shown that uneven distribution of precipitation (drought or excessive moisture) during sowing and in the early stages of

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crop development creates obstacles to the effective action of soil (pre-emergence) herbicides, and the addition of adjuvants to them has a positive effect on the growth, development and formation of sunflower seed productivity. In the conditions of the Western Forest-Steppe (Ternopil region), the best results when using pre-emergence herbicide protection of sunflower were recorded in the variant where Soranet, CE (propizochlor, 720 g/l) – 2.0 l/ha + Idaho, KS (terbutylazine, 500 g/l) 1.5 l/ha was applied, and Peritera adjuvant 0.2 l/ha was added to the specified tank mixture. The use of this soil protection scheme for the crop under study ensured the lowest number of segetal vegetation in the agrocenoses of annual sunflower. In addition, the highest chlorophyll content and low phytotoxicity of the used preparations in relation to cultivated plants were noted. The use of surfactants, which, on the one hand, prevent the movement of active substances to the lower horizons and, on the other hand, ensure better penetration into the soil during moisture shortages, can help to mitigate adverse factors. The results obtained are the basis for improving the elements of sunflower cultivation technology and will ensure a seed yield of 3.58 t/ha and can be used in agricultural formations in Ukraine

Keywords: *Helianthus annuus* L; segetal vegetation; plant protection products; surfactants; phytotoxicity; productivity; oil content

INTRODUCTION

Among the limiting factors that affect the yield of sunflowers, as one of the key export-oriented crops, the determining role belongs to the segetal vegetation, which requires mandatory control. The need for herbicide protection as a central agrotechnological measure for obtaining high yields of the crop under study is due to the fact that, as noted by S. Masliiov *et al.* (2021), weeds can significantly reduce its seed productivity, which will negatively affect foreign exchange earnings in the budget. According to A. Shuvar *et al.* (2021), Yu. Tarasovskyi (2025), sunflower oil is central in the structure of agricultural products in Ukraine, 5.1 billion USD or almost 21%, which exceeds the volumes of corn (5.0 billion USD) and wheat (3.7 billion USD).

According to M. Özkil *et al.* (2022), weed infestation of sunflower agrocenoses is especially harmful during the herbicidal period, which is long and falls on the phases V2-V3 to R3-R5. Weeds compete with cultivated plants for light, moisture and nutrients. According to V. Zuza *et al.* (2022), I. Mostoviak *et al.* (2024), control of segetal vegetation in sunflower crops is conducted by applying soil (pre-emergence) and insurance (post-emergence) herbicides. In Ukraine, the most common active substances used to protect agrocenoses of the crop under study from weeds in the pre-germination period are propizochlor, acetochlor, s-metolachlor, dimethanamide-P, terbutylazine, flufenacet, aclonifen and their mixtures (State Register…, n.d.). At the same time, only aclonifen, terbutylazine and flufenacet are used in the European Union (Pesticide Properties Data Base, n.d.).

The effectiveness of pre-emergence herbicides depends on soil, weather and climatic conditions at the initial stages of sunflower growth and development. On light-texture soils with low cation exchange capacity, active substances can move into the lower soil layers and cause phytotoxicity to crops. Thus, according to Z. Pacanoski and A. Mehmeti (2021), oxyfluorfen, aclonifen, acetochlor, dimethanamid-p, and propizochlor do not significantly reduce their effectiveness at low soil moisture, while the effectiveness of linuron, prosulfocarb and petoxamide depends more on soil moisture. One of the ways to increase the effectiveness of soil herbicides under adverse weather conditions and reduce their phytotoxicity is to use adjuvants. Adjuvants are substances that are added to the solution of plant protection products to increase the effectiveness of pesticide active ingredients (Legleiter *et al.*, 2024).

According to H. Gonçalves *et al.* (2024), adjuvants significantly increase the effectiveness of soil herbicides, and this effect can, in some cases, be twice as high as the control without their use. The addition of adjuvants to soil herbicides improves the adsorption of active substances by the soil, which in turn prevents their movement to the lower horizons, keeping them in the 0-5.0 cm layer and protecting them from photolysis under the influence of sunlight. However, according to W. Grichar and J. McGinty (2022), adjuvants do not always increase the effectiveness of soil herbicides, which probably depends on the agroclimatic conditions of the region and the properties of the surfactants themselves. In addition, the study determined that adjuvants do not reduce the evaporation of applied plant protection products but rather increase it in some cases.

Addressing the ambiguity of research results on the use of surfactants in herbicide crop protection technologies, the study aimed to analyse the effectiveness of soil herbicide formulations with Peritera adhesive pre-emergence on annual sunflower crops. The study aimed to study the peculiarities of growth, development and formation of seed productivity of annual sunflower depending on the options for pre-emergence herbicide protection of crops.

MATERIALS AND METHODS

The field research was conducted in the Western Forest-Steppe of Ukraine at Agrarian Marka Limited Liability Company in Ternopil district, Ternopil region, during 2022-2024. The soil of the experimental field is dark grey podzolised medium loamy with an organic matter content of 3.1%. The scheme of the experiment included the study of six variants of herbicide protection of sunflower hybrid LG 5478 (Table 1).

***Table 1**. Experiment design*

No.	Experiment variants
1	Control without herbicides
2	Tank mix of herbicides SoraNet, CE (propizochlor, 720 g/l) 2.0 l/ha + Idaho, KS (terbutylazine, 500 g/l) 1.5 l/ha
3	Tank mix of herbicides Soranet, CE (propizochlor, 720 g/l) 2.0 l/ha + Idaho, KS (terbutylazine, 500 g/l) 1.5 l/ha + Peritera adjuvant 0.15 l/ha
4	Tank mix of herbicides Soranet, CE (propizochlor, 720 g/l) 2.0 l/ha + Idaho, KS (terbutylazine, 500 g/l) 1.5 l/ha + Peritera adjuvant 0.2 l/ha
5	Tank mixture of herbicides SoraNet, KE (propyzochlor, 720 g/l) 2.0 l/ha + Idaho, KS (terbuthylazine, 500 g/l) 1.5 l/ha + adjuvant Peritera 0.25 l/ha
6	Tank mix of herbicides Soranet, CE (propizochlor, 720 g/l) 2.0 l/ha + Idaho, KS (terbutylazine, 500 g/l) 1.5 l/ha + Peritera adjuvant 0.30 l/ha

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

The area of the registered plots is 100 m^2. The repetition is four times. The studies were conducted following the generally accepted methods of V. Polozhenets *et al.* (2024). A characteristic feature of the weather conditions in the Ternopil region in 2001-2024 is that they reflect these indicators on a global scale and are manifested in the increase in the aridity of the growing season in 2022-2024 (Table 2).

***Table 2**. Sum of precipitation by months of vegetation of crops in the Ternopil region, mm*

Years	Months						
	April	May	June	July	August	September	For the period April-September
2001	53	45	154	135	51	156	594
2002	46	52	82	54	55	70	359
2003	22	49	33	137	32	42	315
2004	21	63	45	94	87	41	351
2005	55	56	67	47	113	11	349
2006	40	79	81	61	184	18	463
2007	18	59	55	114	80	90	416
2008	125	65	39	169	50	138	586
2009	33	59	116	43	28	18	297
2010	48	130	129	107	63	80	557
*	**46.1**	**65.7**	**80.1**	**96.1**	**74.3**	**66.4**	**428.7**
V, %*	66.9	37.3	51.1	45.5	62.3	76.0	26.6
2011	32	37	82	93	39	14	297
2012	62	64	116	78	84	54	458
2013	39	96	137	91	35	78	476
2014	35	124	38	70	87	27	381
2015	30	65	49	41	17	54	256
2016	84	42	151	38	23	73	411
2017	52	72	68	53	37	124	406
2018	15	49	84	87	35	25	295
2019	25	121	54	30	22	10	262
2020	16	60	123	94	81	82	456
$\bar{X}_*$	**39.0**	**73.0**	**90.2**	**67.5**	**46.0**	**54.1**	**369.8**
V, %*	55.2	42.3	43.7	36.9	59.2	66.7	48.7
2021	10	53	41	101	48	58	311
2022	28	17	13	82	78	107	325
2023	73	23	86	84	47	4	317
2024	41	23	45	61	35	82	287

Table 2. Continued

Years	Months						
	April	May	June	July	August	September	For the period April-September
$\bar{X}_*$	38.0	29.0	46.3	82.0	52.0	62.8	**310.0**
V, %*	69.9	56.0	65.0	20.0	35.2	70.1%	48.9
Long-term averages	43	66	80	87	67	58	401

Note: *$\bar{X}$ – Average value of the indicator for the period; V – coefficient of variation of the indicator for the period*
Source: *compiled by the authors based on meteorological observations*

Thus, in the period 2001-2010, the average amount of precipitation for April-October was 428.7 mm, in 2011-2020, 369.8 mm, and for the same period in 2021-2024, only 310.0 mm, while the long-term average for the study area is 401 mm. In addition to the deterioration of the atmospheric humidification regime, there is an uneven distribution of precipitation over the years of observation, as the coefficient of variation is more than 25%, which indicates a significant variability of this indicator. The most common indicator that characterises the variability of weather elements is the coefficient of deviation, which reflects the value of the current value from the long-term average and is determined by the formula.

$$\mathrm{Kc} = \frac{X_i - \bar{X}}{\sigma}, \quad (1)$$

where Kc – deviation significance coefficient; X_i – current weather elements; $\bar{X}$ – average long-term value indicator; σ – standard deviation.

If the coefficient of significance of deviations is at the level of 0-1, the weather conditions are close to normal; at the value of Kc 1-2, the weather conditions are very different from the long-term average; at Kc > 2, the conditions are close to rare M. Kulbida *et al.* (2009) calculated the coefficients of significance of deviations in precipitation and found that there is a tendency to increase the number of atypical months in terms of atmospheric moisture regime (Table 3).

Table 3. *Significance coefficients of deviations of precipitation from long-term averages in the Ternopil region*

Years	Months						Number of atypical months, pcs.
	April	May	June	July	August	September	
2001	0.434	-0.771	2.103	1.265	-0.525	2.766	23
2002	0.126	-0.511	0.060	-0.887	-0.394	0.340	
2003	-0.932	-0.622	-1.331	1.318	-1.147	-0.450	
2004	-0.976	-0.102	-0.990	0.175	0.654	-0.478	
2005	0.522	-0.362	-0.366	-1.073	1.506	-1.324	
2006	-0.139	0.493	0.031	-0.701	3.831	-1.127	
2007	-1.109	-0.251	-0.706	0.707	0.425	0.904	
2008	3.608	-0.027	-1.161	2.168	-0.558	2.258	
2009	-0.447	-0.251	1.025	-1.180	-1.278	-1.127	
2010	0.214	2.390	1.394	0.521	-0.132	0.622	
2011	-0.491	-1.069	0.060	0.149	-0.918	-1.240	23
2012	0.831	-0.065	1.025	-0.250	0.556	-0.111	
2013	-0.183	1.125	1.621	0.096	-1.049	0.566	
2014	-0.359	2.167	-1.189	-0.462	0.654	-0.873	
2015	-0.580	-0.027	-0.877	-1.233	-1.638	-0.111	
2016	1.801	-0.883	2.018	-1.312	-1.442	0.425	
2017	0.390	0.233	-0.338	-0.914	-0.983	1.863	
2018	-1.241	-0.622	0.117	-0.011	-1.049	-0.929	
2019	-0.800	2.055	-0.735	-1.525	-1.474	-1.353	
2020	-1.197	-0.213	1.223	0.175	0.458	0.679	
2021	-1.461	-0.474	-1.104	0.361	-0.623	0.002	10
2022	-0.668	-1.812	-1.898	-0.143	0.359	1.384	
2023	1.316	-1.589	0.173	-0.090	-0.656	-1.522	
2024	-0.095	-1.589	-0.990	-0.701	-1.049	0.679	

Source: *compiled by the authors*

In 2001-2010, the number of months with precipitation amounts significantly different from long-term averages was 23, of which 7 were abnormal. For the period 2011-2020, 23 atypical cases were also recorded, of which only 1 was rare. In 2021-2024, there were already 10 months with precipitation amounts that significantly differed from the long-term average. This indicates a tendency to increase the uneven distribution of precipitation during the growing season and necessitates the use of adjuvants in soil (pre-emergence) herbicide technologies to improve their effectiveness. Directly during the years of research (2022-2024), the weather conditions during sowing and application of soil herbicides in the pre-emergence period differed from the average long-term data, which was used to objectively assess the studied factor under different meteorological indicators (Table 4).

***Table 4**. Agrometeorological conditions at the time of sowing and the beginning of the sunflower growing season, mm*

Year	Months	
	April	May
Sum of precipitation, mm		
2022	38	16
2023	75	12
2024	45	17
Long-term averages	43	66
Air temperature, °C		
2022	7.1	14.9
2023	8.2	14.8
2024	12.3	16.1
Long-term averages	8.7	14.1

***Source:** compiled by the authors based on meteorological observations*

Thus, in 2022, the amount of precipitation in April was 38 mm, and the average daily air temperature was +7.1°C; in 2023 and 2024, respectively, 75 mm and +8.2°C and 45 mm and 12.3°C. The long-term meteorological indicators were 43 mm and +8.7°C, respectively. May 2022-2024 was dry, with 16, 12 and 17 mm of precipitation, respectively, compared to the average long-term norm of 66 mm. The air temperature was +14.9°C in 2022, +14.8°C in 2023 and 16.1°C in 2024. The long-term average was 14.1°C. Thus, April 2022 was cool with a slight deficit of precipitation, 2023 was excessively wet and cold, and May was dry with air temperatures close to the climatic norm. In 2024, April was characterised by sufficient precipitation and above-normal temperatures, while May was dry and excessively warm.

Soil herbicides were applied immediately after sowing the test crop. The working fluid consumption was 200 litres per 1 ha. Weed counts were conducted on permanently fixed plots of 1 m^2. The leaf surface area of the crop under study was determined by the calculation method, the essence of which is that this indicator was calculated by multiplying the length of the leaf by its width and by a conversion factor of 0.74. The sample size of the plants was 20 pieces. The chlorophyll content was determined using the N-tester (Germany), analysing the 30 youngest fully developed leaves. The higher the index, the higher the chlorophyll content and, accordingly, the plants are less affected by stress factors. Harvesting was conducted by threshing the entire experimental plot. The oil content was determined using a FOSS Infratec Nova device (Denmark). For the research, average samples were taken from each replication, weighing 2 kg, which were placed in the device and the oil content was displayed on the screen. The use of this device for research is not subject to copyright infringement restrictions. The authors adhered to the standards of the Convention on Biological Diversity (1992). The cost-effectiveness of the research was conducted based on the developed technological maps, addressing current prices for work performed and material resources as of 2025.

RESULTS AND DISCUSSION

Practical experience in the use of soil (pre-emergence) herbicides shows that one of the main prerequisites for their effective operation and safety for crops is optimal soil moisture. Insufficient moisture partially or completely reduces the effectiveness of soil herbicides, while excessive rainfall can cause the active ingredients to be washed into the lower soil layers, which causes phytotoxicity to crops. However, in actual production conditions, there are rarely favourable conditions for the maximum effectiveness of soil herbicides, as technological operations related to agricultural production are conducted in the open field, where the amount of precipitation is determined by weather conditions.

According to the results of field studies conducted in 2022-2024, a positive effect of the soil adhesive Peritera on the processes of growth, development and formation of seed productivity of annual sunflower was revealed. It was found that the addition of Peritera adjuvant to the tank mixture of herbicides reduced the number of segetal vegetation in the agrocenosis of the studied crop (Table 5). The main representatives of weeds in the experiments were white quinoa (*Chenopodium album* L.) and chicken millet (*Echinochloa crus-galli* L.). The highest weed infestation of sunflower crops was observed in the control without herbicide protection – 35.6 plants per m^2. Pre-emergence application of a tank mixture of soil herbicides with the active ingredients propizochlor, 720 g/l at a rate of 2.0 l/ha and terbutylazine (500 g/l), 1.5 l/ha, helped to reduce the number of segetal vegetation to 5.9 pcs/m^2. The addition of Peritera adjuvant enhanced the effectiveness of the applied products, as the number of weeds was 1.3-2.6 pcs/m^2, which is statistically significant compared to the variant without its use.

A comparative assessment of the application rates of Peritera soil adhesive indicates that it is advisable to use 0.2 l/ha, since further increases do not provide a significant reduction in the number of weeds. Reducing the rate to 0.15 l/ha provides less control of segetal vegetation. It should be noted that the use of adjuvants with soil herbicides is intended not only to enhance the effect of the latter, but also to reduce their possible phytotoxic effects on cultivated plants. One of the indicators that characterise the state of a plant organism is the leaf surface area and the intensity of green colour of the leaves, which in turn is determined by the chlorophyll content. Studies have shown that herbicide protection schemes affected the photosynthetic activity of sunflower plants (Table 6).

***Table 5**. Weed infestation of annual sunflower agrocenoses, depending on the experiment variant, pcs/m^2 (average for 2022-2024)*

Experiment variants	Number of weeds in the 8-leaf stage
Control without herbicides	35.6
Tank mix of herbicides SoraNet, CE (propizochlor, 720 g/l) 2.0 l/ha + Idaho, KS (terbutylazine, 500 g/l) 1.5 l/ha	5.9
Tank mix of herbicides Soranet, CE (propizochlor, 720 g/l) 2.0 l/ha + Idaho, KS (terbutylazine, 500 g/l) 1.5 l/ha + Peritera adjuvant 0.15 l/ha	2.6
Tank mix of herbicides Soranet, CE (propizochlor, 720 g/l) 2.0 l/ha + Idaho, KS (terbutylazine, 500 g/l) 1.5 l/ha + Peritera adjuvant 0.20 l/ha	1.9
Tank mixture of herbicides SoraNet, KE (propyzochlor, 720 g/l) 2.0 l/ha + Idaho, KS (terbuthylazine, 500 g/l) 1.5 l/ha + adjuvant Peritera 0.25 l/ha	1.5
Tank mix of herbicides Soranet, CE (propizochlor, 720 g/l) 2.0 l/ha + Idaho, KS (terbutylazine, 500 g/l) 1.5 l/ha + Peritera adjuvant 0.30 l/ha	1.3
LSD_{05}, pcs/m^2*	0.6

***Note:** Least significant difference (LSD) indicates a significant reduction in weed infestation from herbicide application and its absence between adjuvant application rates*
***Source:** compiled by the authors*

***Table 6**. Main indicators of photosynthetic activity of sunflower crops in the 6-leaf stage, depending on herbicide protection schemes (average for 2022-2024)*

Experiment variants	Area of sunflower crop leaf surface, thousand m^2/ha	Chlorophyll content in leaves, N-tester units
Control without herbicides	2.95	489
Tank mix of herbicides SoraNet, CE (propizochlor, 720 g/l) 2.0 l/ha + Idaho, KS (terbutylazine, 500 g/l) 1.5 l/ha	3.25	496
Tank mix of herbicides Soranet, CE (propizochlor, 720 g/l) 2.0 l/ha + Idaho, KS (terbutylazine, 500 g/l) 1.5 l/ha + Peritera adjuvant 0.15 l/ha	3.62	511
Tank mix of herbicides Soranet, CE (propizochlor, 720 g/l) 2.0 l/ha + Idaho, KS (terbutylazine, 500 g/l) 1.5 l/ha + Peritera adjuvant 0.20 l/ha	4.65	551
Tank mixture of herbicides SoraNet, KE (propyzochlor, 720 g/l) 2.0 l/ha + Idaho, KS (terbuthylazine, 500 g/l) 1.5 l/ha + adjuvant Peritera 0.25 l/ha	4.71	564
Tank mix of herbicides Soranet, CE (propizochlor, 720 g/l) 2.0 l/ha + Idaho, KS (terbutylazine, 500 g/l) 1.5 l/ha + Peritera adjuvant 0.30 l/ha	4.75	570
LSD_{05}*	0.63	32

***Note:** Least significant difference (LSD) indicates a significant reduction in weed infestation from herbicide application and its absence between adjuvant application rates*
***Source:** compiled by the authors*

LSD (least significant difference) indicates a reliable increase in the leaf surface area of plants and chlorophyll content in leaves from the application of herbicides and their absence between the application rates of adjuvants. The use of soil herbicides that control weeds in the study crop contributed to the growth of the leaf area of the sunflower. Thus, in the variant without the use of adjuvants, this indicator was at the level of 3.25 thousand m^2/ha, when adding Peritera adhesive to the tank mixture at a rate of 0.15 l/ha, it was 3.62 thousand m^2/ha, and when adding 0.2, 0.25 and 0.3 l/ha, it was 4.65, 4.71 and 4.75 thousand m^2/ha, respectively. Statistical processing of the research results indicates that there is no significant difference between the application of 0.20, 0.25 and 0.3 l/ha of Peritera adjuvant.

The chlorophyll content in sunflower leaves depended on the herbicide protection scheme. Thus, in the control without the use of plant protection products, it was the lowest and was at the level of 489 units. The use of a tank mix of herbicides with the active ingredients propizochlor, 720 g/l and terbutylazine, 500 g/l, contributed to an increase in the chlorophyll content in the leaves to 496 units due to the reduction of the negative impact of segetal vegetation on cultivated plants. The addition of Peritera adhesive to the tank mixture of herbicide active ingredients led to an increase in the intensity of green colour of sunflower leaves, which was reflected in the increase in the accumulation of green pigments in photosynthetically active organs. Thus, in the variant with the application of 0.15 l/ha, the N-tester readings were 511 units. Further increase in the rate of soil adhesive application contributed to the accumulation of chlorophyll content in the leaves, but its maximum statistically confirmed content was noted in the variant with the use of 0.2 l/ha 551 units. Studies have shown that variants of herbicide protection affected the seed productivity of sunflower (Table 7).

***Table 7**. Key indicators of seed productivity of sunflower crops depending on herbicide protection schemes (average for 2022-2024)*

Experiment variants	Seed yield, t/ha	Oil content in seeds, %
Control without herbicides	1.62	42.2
Tank mix of herbicides SoraNet, CE (propizochlor, 720 g/l) 2.0 l/ha + Idaho, KS (terbutylazine, 500 g/l) 1.5 l/ha	3.31	48.9
Tank mix of herbicides Soranet, CE (propizochlor, 720 g/l) 2.0 l/ha + Idaho, KS (terbutylazine, 500 g/l) 1.5 l/ha + Peritera adjuvant 0.15 l/ha	3.45	49.0
Tank mix of herbicides Soranet, CE (propizochlor, 720 g/l) 2.0 l/ha + Idaho, KS (terbutylazine, 500 g/l) 1.5 l/ha + Peritera adjuvant 0.20 l/ha	3.58	49.3
Tank mixture of herbicides SoraNet, KE (propyzochlor, 720 g/l) 2.0 l/ha + Idaho, KS (terbuthylazine, 500 g/l) 1.5 l/ha + adjuvant Peritera 0.25 l/ha	3.61	49.5
Tank mix of herbicides Soranet, CE (propizochlor, 720 g/l) 2.0 l/ha + Idaho, KS (terbutylazine, 500 g/l) 1.5 l/ha + Peritera adjuvant 0.30 l/ha	3.65	49.5
LSD_{05}	0.11	0.51

***Note:** LSD (least significant difference) indicates a reliable increase in seed yield and oil content in seeds from the application of herbicides and their absence between the application rates of adjuvants*
***Source:** compiled by the authors*

Among the options studied, the lowest seed yield was observed in the control without herbicides, where, due to the intensive development of segetal vegetation, the seed yield per unit area was 1.62 t/ha. The oil content in the seeds was also the lowest and amounted to 42.2%. The application of a tank mixture of soil herbicides with the active ingredients propyzochlor, 720 g/l, and terbuthylazine, 500 g/l, followed by the application of insurance preparations, contributed to an increase in seed productivity to 3.31 t/ha and oil content to 48.9%. Depending on the application rate of the soil adjuvant, the sunflower seed yield was 3.453.65 t/ha. The minimum application rate of the Peritera adjuvant (0.15 l/ha) ensured seed productivity of the tested crop at 3.45 t/ha with an oil content of 49.0%. This is 0.14 t higher than the production control. In the experiment with the application of 0.2 l/ha of Peritera, an increase in sunflower yield to 3.58 t/ha was noted, which is 0.27 t/ha more than the production control. The oil content was 49.3% (Table 7, option 3).

Further increase in the rate of soil adjuvant application, although it provides an increase in the seed productivity of the crops under study, this increase is within the statistical error. Studies have shown that herbicide protection options provided different economic efficiency (Table 8). As of 1.02.2025, the average selling price of sunflower seeds in Ukraine was 25000 UAH/t, and the cost of Peritera soil adhesive was 780 UAH/l. Depending on the variant of the experiment, the cost of increasing the yield of sunflower seeds relative to the absolute control was 1,692.06 t/ha, and relative to the production control, 0,140.37 t/ha. In monetary terms, these figures amounted to 4225051500 and 35009250 UAH/ha, respectively. The highest yield increases in physical and monetary terms were observed in the variant with 0.3 l/ha of Peritera soil adjuvant, 2.06 t/ha and 51500 UAH/ha relative to the absolute control and 0.37 t/ha and 9250 UAH/ha compared to the production control.

***Table 8**. Main indicators of the efficiency of soil herbicide protection of sunflower (average for 2022-2024)*

Experiment variants	Seed yield, t/ha	Yield increases to absolute control, t/ha	Yield increases to production control, t/ha	Cost of yield increase to absolute control, UAH/ha	Cost of crop growth to production control, UAH/ha	Cost of adhesive application, GBP/ha	Contingent net profit from the use of adhesive, UAH/ha	Level of profitability of soil adhesive application, %	Sunflower equivalent, application of soil adhesive, kg/ha
Control without herbicides	1.62	-	-	-	-	-	-	-	-
Tank mix of herbicides SoraNet, CE (propizochlor, 720 g/l) 2.0 l/ha + Idaho, KS (terbutylazine, 500 g/l) 1.5 l/ha	3.31	1.69	-	42,250	-	-	-	-	-
Tank mix of herbicides Soranet, CE (propizochlor, 720 g/l) 2.0 l/ha + Idaho, KS (terbutylazine, 500 g/l) 1.5 l/ha + Peritera adjuvant 0.15 l/ha	3.45	1.83	0.14	45,750	3,500	117	3,383	2,891.5	4.68
Tank mix of herbicides Soranet, CE (propizochlor, 720 g/l) 2.0 l/ha + Idaho, KS (terbutylazine, 500 g/l) 1.5 l/ha + Peritera adjuvant 0.20 l/ha	3.58	1.96	0.27	49,000	6,750	156	6,594	4,226.9	6.24
Tank mixture of herbicides SoraNet, KE (propyzochlor, 720 g/l) 2.0 l/ha + Idaho, KS (terbuthylazine, 500 g/l) 1.5 l/ha + adjuvant Peritera 0.25 l/ha	3.61	1.99	0.30	49,750	7,500	195	7,305	3,746.2	7.80
Tank mix of herbicides Soranet, CE (propizochlor, 720 g/l) 2.0 l/ha + Idaho, KS (terbutylazine, 500 g/l) 1.5 l/ha + Peritera adjuvant 0.30 l/ha	3.68	2.03	0.34	50,750	8,500	234	8,266	3,532.5	9.36

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

Considering the price of 1 litre of Peritera soil adhesive 780 UAH/l and the absence of additional costs for its application, as it is added to the tank mixture of soil herbicides, the cost of treating 1 ha with it is 117234 UAH. In the variant where the application rate was 0.15 l/ha, this figure was the lowest and was at 117 UAH/ha, and when using 0.3 l/ha of the product, it was the highest at 234 UAH/ha. In Ukraine, several studies have been conducted to investigate the impact of soil (pre-emergence) herbicides on the seed productivity of annual sunflower. For example, according to O. Rudik *et al.* (2020), the active ingredients oxyfluorfen, terbuthylazine, acetochlor, promethrin, pendimethalin, S-metholachlor, and propizochlor are used to control segetal vegetation in the agrocenoses of the crop. In addition, according to M. Radchenko *et al.* (2022), a tank mix of herbicides with the active ingredients flumioxazin and fluorochloridone is quite effective.

V. Gurtovenko and O. Tsyuk (2024) established that, for conditions in the Cherkasy region, the best option for weed control in sunflower agrocenoses is the application of 5 l/ha of the herbicide Challenge. At the same time, the highest seed yield of the studied crop was 3.8 t/ha. The high efficiency of the tank mixture of soil herbicides Challenge (2.5 l/ha) + Harness (1.5 l/ha) was proven by V. Hryhoriev and A. Fedchuk (2021) in the conditions of the Khmelnytskyi region, which ensured the highest seed yield of the studied hybrids, 3.03.47 t/ha. When studying the effect of soil herbicides on biometric indicators and sunflower yield, authors S. Mazur and H. Matusevych (2023) found that the application of the preparation Gezagard proved to be the most effective and ensured a seed yield of 2.64 t/ha, which was 23.9% higher than the control.

The use of weed control products during the period of VVSN 00-09 is advisable even in crops of hybrids grown using ExpressSun technology, as proven in the experiments of G. Delchev *et al.* (2020). Notably, according to Z. Pacanoski and A. Mehmeti (2021), in dry conditions, the effect of pre-emergence herbicides is reduced, and in conditions of sufficient moisture, their high efficiency is ensured. In this context, it is necessary to create conditions to ensure the maximum effectiveness of soil herbicides, as F. Önemli and Ü. Tetik (2023) found that post-emergence herbicides used to control segetal vegetation harm the growth, development and formation of sunflower seed productivity.

However, according to the literature, despite a significant number of experiments on the effectiveness of pre-emergence control of segetal vegetation of sunflower agrocenoses, the issue of using adjuvants in herbicide protection technologies has not been studied in Ukraine. At the same time, the State Register of Pesticides and Agrochemicals Approved for Use in Ukraine (State Register... (n.d.) includes a significant number of such products, and they are widely used in production conditions of agricultural enterprises in different regions of the country. However, abroad, in the European Union and other countries, adjuvants are widely used in crop cultivation technologies, in terms of their chemical protection against harmful objects, including weeds. They help to increase the effectiveness of crop protection products and reduce the application rates and the number of chemical treatments.

According to research conducted by scientists around the world, the use of adhesives for soil (pre-emergence) herbicides is an ambiguous issue and therefore requires more detailed study. According to N. Sharma *et al.* (2020), the addition of adjuvants to soil herbicides results in better soil absorption of the active components of herbicides, which improves the environmental component of their use. However, production experience and research results, as noted by W. Grichar and J. McGinty (2022), on the use of these substances in pre-emergence herbicide protection technologies for crops, including sunflower, indicate that the obtained indicators are controversial. This is manifested in the insufficient effectiveness of the applied preparations, the lack of evaporation reduction, or even its increase, as reported by S. Das and K. Hageman (2020). Thus, modern crop cultivation technologies should be based on adaptation to specific soil and climatic conditions to ensure the highest efficiency of agrotechnical measures and create preconditions for obtaining high yields with appropriate quality and economic efficiency indicators.

CONCLUSIONS

Long-term studies have shown that the addition of adjuvants to soil herbicides has a positive effect on the growth, development and formation of sunflower seed productivity. On average, over the three years of research, the best statistically proven herbicide protection option was the application of a tank mix of Soranet, CE (propizochlor, 720 g/l) 2.0 l/ha + Idaho, KS (terbutylazine, 500 g/l) 1.5 l/ha + Peritera adjuvant 0.2 l/ha. This variant of the experiment showed the lowest weediness of crops and the lowest manifestation of phytoxicity, since the N-tester indicators and, consequently, the chlorophyll content were the highest. The seed yield of the crop under study was 3.58 t/ha, and the oil content was 49.3%. The use of Peritera soil adhesive was profitable in all variants of the experiment, as the low cost of its application was paid off by significant yield increases. The highest profitability was observed in the variant with a rate of 0.2 l/ha of the adjuvant – 42-26.9%.

The use of Peritera soil adhesive was profitable in all variants of the experiment, as the low cost of its application was paid off by significant yield increases. The highest profitability was recorded in the variant with a rate of 0.2 l/ha of adjuvant, which was 42-26.9%. Another indicator of the effectiveness and feasibility of Peritera is the equivalent of the grown product (sunflower seeds) required for its application. Thus, considering the cost of 1 tonne of sunflower seeds at 25,000 UAH/t, the cost of using the adhesive is 4,68-9.36 kg/ha of sunflower seeds, while the yield increase from its application is 140-340 kg/ha. Given that the use of adjuvants in pre-emergence herbicide crop protection technologies in Ukraine is completely unexplored, this issue is highly relevant in the context of climate change and in the context of reducing the pesticide burden on the environment.

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CONFLICT OF INTEREST

None.

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Ефективність використання ад'ювантів при застосуванні досходових гербіцидів на посівах соняшнику однорічного

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Анотація. Використання ад'ювантів у системах хімічного захисту посівів від шкідливих об'єктів, зокрема і бур'янів є однією із важливих інновацій у сільськогосподарському виробництві. Метою досліджень було вивчити ефективність застосування різних норм ад'юванта Peritera в системі досходового гербіцидного захисту соняшнику однорічного (*Helianthus annuus* L.) в умовах західного Лісостепу. Методи досліджень: польовий, лабораторний, кількісний, математично-статистичний для оцінювання достовірності отриманих даних. Багаторічними дослідженнями було встановлено, на фоні нерівномірного розподілу опадів (посуха або надмірне зволоження) під час сівби та на початкових етапах розвитку сільськогосподарських культур, створюються перешкоди для ефективної дії ґрунтових (досходових) гербіцидів, а додавання ад'ювантів до них позитивно впливає на процеси росту, розвитку та формування насіннєвої продуктивності соняшнику. В умовах Західного Лісостепу (Тернопільська область) найкращі результати при використанні досходового гербіцидного захисту соняшнику зафіксовано на варіанті, де вносилися препарати СораНет, КЕ (пропізохлор, 720 г/л) – 2,0 л/га + Айдахо, КС (тербутилазин, 500 г/л) – 1,5 л/га і в зазначену бакову суміш було додано ад'ювант Peritera 0,2 л/га. Застосування цієї ґрунтової схеми захисту для досліджуваної культури забезпечило найменшу чисельність сегетальної рослинності в агроценозах соняшнику однорічного. Крім цього відмічено найвищий вміст хлорофілу та низьку фітотоксичність використовуваних препаратів у відношенні до культурних рослин. Через застосування поверхнево-активних речовин, які з одного боку запобігають переміщенню діючих речовин в нижні горизонти, а з іншого забезпечують краще їх проникнення в ґрунт під час нестачі вологи можливе нівелювання несприятливих факторів. Отримані результати є основою для вдосконалення елементів технології вирощування соняшнику та забезпечать урожайність насіння на рівні 3,58 т/га і можуть застосовуватися в агроформуваннях України

Ключові слова: *Helianthus annuus* L; сегетальна рослинність; засоби захисту рослин; поверхнево-активні речовини; фітотоксичність; продуктивність; олійність