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Herbicide influence on the agrocenose of soy and its photosynthetic activity in the western Forest Steppe of Ukraine

Ivan Shuvar
Doctor of Agriculture, Professor
Lviv National Environmental University
80381, 1 V. Velykyi Str., Dublyany, Lviv Region, Ukraine
https://orcid.org/0000-0002-4149-1761

Hanna Korpita*
PhD in Agriculture, Associate Professor
Lviv National Environmental University
80381, 1 V. Velykyi Str., Dublyany, Lviv Region, Ukraine
https://orcid.org/0000-0002-0908-0129

Abstract. The use of herbicides can significantly affect the processes of plant photosynthesis, as it leads to inhibition of pigment production, impairs the transport of electrons in the respiratory chain and carbon fixation. The purpose of the study is to determine the effect of herbicide application on weediness and photosynthetic activity of soybeans. On the basis of a field study in the conditions of the Educational and Scientific Center of the Lviv National University of Nature Management, the dependence of soybean yield on the level of weediness of the culture was established. The highest yield of soybeans – 29.0 t/ha was obtained in the application of the herbicide Primekstra TZ Gold 500 SC c.s. (4.5 l/ha), the smallest – 27.3 t/ha among the experimental variants was obtained with the post-emergence application of the herbicide Pulsar s.c. (1 l/ha). Application of herbicide Primekstra TZ Gold 500 SC c.s. did not affect the intensity of photosynthesis, and the number of pigments in soybean leaves was not significantly different from the indicator in the control. The use of drugs Kommand k.e. and Pulsar s.c. led to a slight decrease in the number of pigments in the first days after application and their gradual stabilization. Use of the herbicide Concur c.s. had the effect of weakening photosynthetic activity and reducing the number of pigments. This indicates that the active substance metribuzin is not absolutely selective with regard to the effect on soybean plants, that is, in the case of its use, there is a probability of suppressing the culture. The practical significance of the obtained results lies in revealing the possibilities for choosing effective herbicides with increased selective phytotoxicity, which provide effective control of the number of weeds with a minimal probability of a negative impact of herbicides on the soybean agrocenosis

Keywords: soybean; pigments; active substance; photosynthesis; weeds; productivity

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**Corresponding author*

INTRODUCTION

Photosynthesis is an important process for plant life, as it provides the synthesis of organic compounds necessary for plant growth and development. Herbicides can have a significant negative impact on the photosynthetic activity of plants and lead to a decrease in yield, deterioration of product quality, and threaten the ecosystem. The application of herbicides can have different effects on the photosynthetic activity of plants, since these agents are designed to control weeds and other unwanted plants, and not to directly affect crops. Depending on the used herbicide, dose, time of application and environmental conditions, the effect may be different.

Herbicides that affect the synthesis of amino acids or proteins can reduce the level of photosynthetic pigments and limit the ability of plants to photosynthesize. They can cause oxidative stress in the plant, which can cause cell damage and reduce photosynthetic activity (Nosek *et al.*, 2017; Han *et al.*, 2022).

One of the key reactions of photosynthesis is photochemical electron transport, which is carried out by photosystem complexes centered on chloroplast membranes, herbicides can inhibit the processes of photosynthesis by delaying this electron transport (Gamayunova & Panfilova 2019).

Research by A.T. Taylor & E.P.C. Lai (2021) stablished that, when entering the plant, the active substance glyphosate inhibits the production of the EPSP synthetase enzyme. Inhibition of the activity of this enzyme blocks the formation of aromatic amino acids by plants, important for their growth and components of many plant pigments, the structure and activity of chloroplasts is reflected in the reduced amount or absence of photosynthetic pigments.

However, there is an assortment of herbicides that do not have a negative effect on the photosynthetic activity of plants or can even enhance it. In particular, herbicides that reduce competition with weeds can help plants increase the availability of light, water and nutrients and make them more efficient at photosynthesis (Gomes *et al.*, 2014).

G.B.P. Braz *et al*. (2022) show that herbicides can affect the photosynthetic activity of soybeans by slowing photosynthetic electron transport. Such a process can lead to a weakening of the photosynthesis process and, accordingly, to a decrease in the production of organic substances necessary for plant growth and development. Herbicides can also affect the development of chloroplasts and other cell organelles that affect photosynthetic activity.

Research by J. Constantin *et al*. (2020) established that the introduction of herbicides can reduce the photosynthetic activity of soybeans, in particular, due to a decrease in the amount of chlorophyll in the leaves and an increase in the concentration of reagents that cause oxidative stress in the plant. However, as S. McCown *et al*. (2018) point out, the effect of herbicides on photosynthetic activity may be small or even absent, depending on the specific herbicide and soybean growing conditions.

The purpose of the research was to determine the herbicidal effect on soybean agrocenosis and its photosynthetic activity. To achieve the set goal, the following tasks were completed:

1. The effectiveness of weed control in soybean crops depending on the use of herbicide was investigated.
2. The influence of herbicides on the yield of soybean seeds was established.
3. The effect of herbicides on the pigment content and photosynthetic activity of soybeans was investigated.

MATERIALS AND METHODS

Research on the effectiveness of herbicides on weediness and photosynthetic activity of soybeans was carried out during 2021-2022 in the conditions of the educational and scientific center of the Lviv National Environmental University.

For the study, the precocious soybean variety Ustya was used (originator – NSC "Institute of Agriculture of the National Academy of Sciences of Ukraine"). Soybeans were sown in the usual row method with a row width of 15 cm, with a sowing rate of 650,000 similar seeds per hectare at a soil temperature of 10-12°C at the depth of seed wrapping. The soybean fertilization system included application of 140 kg/ha of ammonium nitrate and 100 kg/ha of ammonium sulfate.

The soybean protection system against weeds involved the application of herbicides with different mechanisms of action, namely: the soil herbicide Primekstra TZ Gold 500 SC (active substance – Metolachlor, Terbuthylazine) before the appearance of seedlings of cultivated plants and post-emergence – in phase 1-3 trifoliate leaves in crops: Kommand (active substance – Clomazone), Pulsar (active substance – Imazamox), Concur (active substance – Metribuzin).

The experiment included four options with 3 repetitions: Variant 1 – control (without application of herbicides); Variant 2 – Primekstra TZ Gold 500 SC c.s. (4.5 l/ha); Variant 3 – Kommand k.e. (0.2 l/ha ha); Variant 4 – Pulsar s.c. (1 l/ha); Variant 5 – Concur c.s. (0.7 l/t). The area on which the experiment was laid is 0.5 ha with randomized placement of plots, the distance between them is 0.4 m.

The level of weediness was measured using a quantitative method with overlapping frames with an area of 0.25 m^2 in four places diagonally. The species diversity of weeds was determined in the seedling phase, flowering and at the time of soybean harvest. The obtained results were compared to the control (variant without herbicide application). The actual weediness of crops was evaluated in points according to the visual-quantitative method of A.G. Maltsev. At the same time, the weediness score was determined both for all types of weeds in general and for their individual types.

The photosynthetic activity of soybeans was determined by CO_2 (carbon dioxide) gas exchange, which was measured using an infrared optical-acoustic gas analyzer. The content of photosynthetic pigments was determined by the method of extracting a portion of plant material in a water bath at a temperature of 67°C for 3 hours (Pradhan *et al.*, 2018). The content of pigments was calculated in μg/mg mass of raw material.

Soybean productivity was calculated by continuous manual harvesting with preliminary mowing of the above-ground mass of plants. Processing of the obtained research results for reliability was carried out using the multivariate MANOVA method of variance analysis using Microsoft Excel software and the Statistica 10 program package. Differences in the obtained results are possible at the level of significance $P \leq 0.05$ according to the Student's test.

The research was conducted in accordance with ethical requirements. Experimental plant studies, including collection of plant material, followed institutional and international guidelines. The research also adhered to the standards of the Convention on Biological Diversity (2022).

RESULTS

During the years of research, it was established that the agrocenosis of soybeans was dominated by one-year weed species, namely: *Setaria glauca* L., *Chenopodium album* L., *Echinochloa crus-galli* L., *Amaranthus retroflexus* L., *Raphanus raphanistrum* L. etc. Of the perennial weed species were *Sonchus arvensis* L., *Equisetum arvense*, *Elytrigia repens*, *Convolvulus arvensis* (Fig. 1).

The share of annual weed species in general was 53-68% of all species, in particular: *Chenopodium album* occupied 10% in the structure of annual weeds, *Convolvulus arvensis* – 12%, *Amaranthus retroflexus* L. – 19%, *Galinsoga parviflora* Cav. – 10%, *Polygonum convolvulus* L. – 13%. About 9-11% were perennial rhizome weeds, in particular *Equisetum arvense* L. and *Elymus repens*.

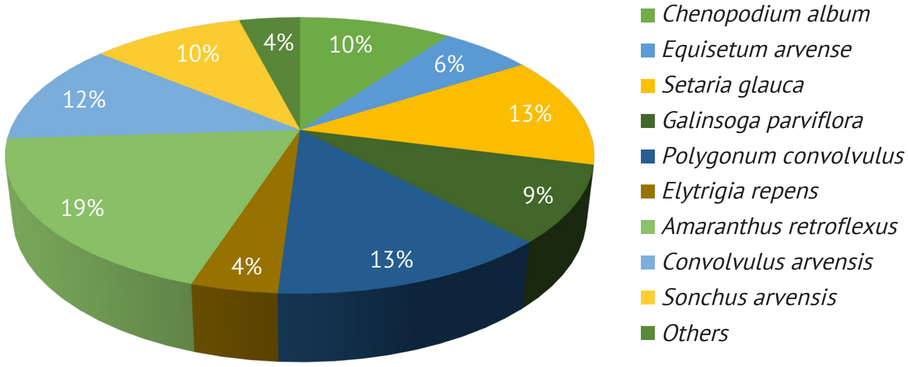

Figure 1. *Main types of weeds in soybean crops, % (average for 2021-2022)*
Source: *developed by authors*

Root weeds accounted for 17-22%, among them were *Sonchus oleraceus, Convolvulus arvensis* L., and dandelion *Taraxacum officinale*.

Over the years of the study, during the growing season of soybeans, records of the dynamics of weediness of crops were made, which made it possible to determine the structure of weediness and to apply herbicides in time and prevent the development of weeds. In the option of using the pre-emergence herbicide Primekstra TZ Gold 500 SC c.s. in the seedling phase of soybeans, there were, on average, the fewest weeds (7 pcs./m^2). This is due to the introduction of post-emergence herbicides in the phase of 1-3 trifoliate leaves in soybeans (Table 1).

Table 1. *Dynamics of weediness of soybean crops, pcs./m^2 (average for 2021-2022)*

Variant	Weed accounting period		
	seedling phase	flowering phase	harvesting
Control (without application of herbicides)	23	62	113
Primekstra TZ Gold 500 SC c.s. (4.5 l/ha)	7	15	22
Kommand k.e. (0.2 l/ha ha)	16	19	24
Pulsar s.c. (1 l/ha)	19	22	26
Concur c.s. (0.7 l/t)	18	20	24

Source: *developed by authors*

At the time of harvesting soybeans, the least weeded on average over the years of the study (22 pcs./m^2) were the crops in the variant of the experiment with the pre-emergence application of the herbicide Primekstra TZ Gold 500 SC c.s. at a rate of 4.5 l/ha, which is 80.5% less compared to the control (113 units/m^2). This introduction made it possible to effectively control grass and dicotyledonous weeds in soybean crops. For post-emergence application of Pulsar s.c. (1 l/ha) at the time of soybean harvest, among the variants of the experiment, the largest number of weeds was established – 26 pcs./m^2.

Observations of the dynamics of the appearance of weeds showed that most of them germinate in the period from the phase of soybean seedlings to budding, then the culture can compete with weeds and inhibit their development. In addition, the lowest indicator of weediness in the seedling phase of soybeans was established at 1-2 points in the variant of using the herbicide Primekstra TZ Gold 500 SC c.s. During this period, annual early spring and late spring types of weeds began to emerge. In the flowering phase of soybeans, in all variants of the experiment, weediness of the crops was 2-3 points. At the time of soybean harvest, weediness of the crops was the highest. The study of the effectiveness of herbicides in soybean crops of the Ustya variety established the effect not only on reducing the number of weeds, but also on increasing the yield of soybeans compared to the control (Table 2).

Table 2. *Effect of herbicides on soybean yield, c/ha*

Variant	Year		Average for 2021-2022	± to control, %
	2021	2022		
Control (without application of herbicides)	24.5	23.7	24.1	-
Primekstra TZ Gold 500 SC c.s. (4.5 l/ha)	28.7	29.3	29.0	+20.3
Kommand k.e. (0.2 l/ha ha)	27.1	28.6	27.9	+15.8
Pulsar s.c. (1 l/ha)	26.9	27.7	27.3	+13.3
Concur c.s. (0.7 l/t)	26.8	27.9	27.4	+13.7
LSD_{05}	1.24	1.32		

Source: *developed by authors*

The highest yield of soybean grain on average for 2021-2022 was obtained in the variant of using the herbicide Primekstra TZ Gold 500 SC c.s. (4.5 l/ha) – 29.0 t/ha, which is 20.3% higher than the control (24.5 t/ha). It was the smallest (27.3 c/ha) in the variant of post-emergence application of the herbicide Pulsar s.c. (1 l/ha). Thus, the yield of soybeans depends on the level of weediness of crops, and the use of herbicides can prevent not only crop yield losses, but also increase it.

The study of the effect of herbicides on the photosynthetic activity of soybeans showed that the introduction of the herbicide Primekstra TZ Gold 500 SC c.s. did not affect the decrease in the intensity of photosynthesis, and the number of pigments in soybean leaves was not significantly different from the control. However, in the case of the use of the drugs Kommand k.e. and Pulsar s.c. a slight decrease in the number of pigments in the period after the application of herbicides, which was accompanied by their stabilization, was established on average over the years of the study. And the introduction of the herbicide Concur c.s. led to a weakening of photosynthetic activity and a decrease in the number of pigments (Table 3; Table 4).

Therefore, the active substance metribuzin is not absolutely selective for soybeans, that is, in the case of its use, there is a probability of suppressing the culture.

Table 3. *Pigment content (µg/mg raw substance) in soybean leaves (average for 2021-2022)*

Variant	2021			2022		
	chlorophyll *a*	chlorophyll *в*	carotenoids	chlorophyll *a*	chlorophyll *в*	carotenoids
Control (without application of herbicides)	1.78	0.64	0.86	1.88	0.71	0.92
Primekstra TZ Gold 500 SC c.s. (4.5 l/ha)	1.69	0.74	0.95	1.92	0.83	0.86
Kommand k.e. (0.2 l/ha ha)	1.76	0.71	0.88	1.93	0.79	0.91
Pulsar s.c. (1 l/ha)	1.80	0.75	0.89	1.89	0.75	0.87
Concur c.s. (0.7 l/t)	1.56	0.35	0.54	1.63	0.39	0.61
LSD_{05}	1.19	1.08	1.31	1.36	1.29	1.46

Source: *developed by authors*

Table 4. *Photosynthetic activity of soybeans, mg CO_2/(dm²×h)*

Variant	2021	2022	Average for 2021-2022
Control (without application of herbicides)	34	36	35
Primekstra TZ Gold 500 SC c.s. (4.5 l/ha)	35	38	36.5
Kommand k.e. (0.2 l/ha ha)	37	36	36.5
Pulsar s.c. (1 l/ha)	36	39	37.5
Concur c.s. (0.7 l/t)	31	29	30
LSD_{05}	1.26	1.64	1.43

Source: *developed by authors*

Application of soil herbicides prior to soybean and weed emergence increases the effectiveness of weed control, soybean yield, and herbicide selectivity relative to the crop.

DISCUSSION

Herbicides are widely used in agriculture to control weeds on agricultural and other lands. However, the research of A. Panfilova *et al.* (2019) proves that the use of herbicides can have a negative effect on the photosynthetic activity of plants. Herbicides can disrupt the natural process of photosynthesis by interfering with key processes such as electron transport, carbon fixation, and pigment production, which also correlates with the study.

The effect of herbicides on the photosynthetic activity of soybean depends on the type of herbicide and the application rate. Some active substances, such as glyphosate, suppress the production of certain amino acids important for protein synthesis, which leads to a weakening of plant growth and photosynthetic activity. Also, glyphosate can reduce the activity of the enzyme ribulose-1.5-bisphosphate carboxylase/oxygenase (Rubisco), which is necessary for carbon fixation in the process of photosynthesis. This can lead to reduced photosynthetic efficiency and reduced plant growth and yield (Korpita & Shuvar, 2020; Soares *et al.*, 2020) In addition, active substances such as atrazine and metribuzin have been shown to disrupt the electron transport chain in photosynthesis, leading to a decrease in energy production and photosynthetic activity (Corrêa & Alves, 2010; Shuvar *et al.*, 2022). Certain herbicides can disrupt the electron transport chain in photosynthesis, which can lead to reduced energy production and photosynthetic activity. For example, atrazine alters the electron transport chain, leading to reduced ATP (Adenosine triphosphate) production and ultimately reduced photosynthesis in plants (Banerjee *et al.*, 2022; Shuvar & Korpita, 2023).

According to the results of the research by S. Kaeoboon *et al.* (2021) and R. Cruz de Carvalho *et al.* (2022), the use of herbicides can affect the processes of CO_2 gas exchange in plants and the efficiency of photosynthesis. Studies have shown that the use of herbicides can reduce the stomatal conductance of plants, thereby limiting the supply of CO_2 to the leaves and accompanied by a decrease in growth and yield of agricultural crops and a weakening of photosynthetic activity, which is also reflected in the performed study. On the other hand, it was established that some herbicides have a positive effect on CO_2 gas exchange. For example, some systemic herbicides can increase the rate of CO_2 assimilation by leaves, which can lead to improved growth and increased crop yields (Iummato *et al.*, 2019; Cavaco *et al.*, 2022).

Cytokinin-based herbicides can actually increase chlorophyll production in plants. Cytokinins are plant hormones that promote cell division and growth and can also stimulate the production of chlorophyll in plants. In addition, certain herbicides can affect the production and activity of photosynthetic pigments, such as carotenoids, which can also affect photosynthesis and plant growth (Jain & Sandhu, 2019).

However, it is worth noting that the effect of herbicides on soybeans can also depend on factors such as plant age and environmental conditions. For example, young soybean plants tend to be more sensitive to herbicides than mature plants, and high temperatures and drought stress can exacerbate the negative effects of herbicide applications. Also important is that the effect of herbicides on photosynthetic activity can vary depending on the specific herbicide, application rate and timing, plant species, and environmental conditions such as temperature and humidity. Therefore, it is extremely important to carefully consider the use of herbicides in agriculture and minimize their negative impact on photosynthesis and plant growth, which is confirmed by the research carried out.

CONCLUSIONS

It has been established that the yield of soybean depends on the weediness of the crops, and when using herbicides, it is possible to prevent crop yield loss and increase its growth. Over the course of the two-year study, it was found that the highest average yield of soybean grain, 29.0 tons per hectare (t/ha), was obtained when using the herbicide Primekstra TZ Gold 500 SC c.s. at a rate of 4.5 liters per hectare (l/ha). The lowest yield rate of 27.3 t/ha among the herbicide options was obtained when the herbicide Pulsar 40 s.c. was applied post-emergence at a rate of 1 l/ha.

The application of the herbicide Primekstra TZ Gold 500 SC c.s. did not result in a reduction of photosynthesis, and the number of pigments in soybean leaves did not show a significant difference compared to the control. However, in the variants where the herbicides Kommand k.e. and Pulsar s.c. were used, a slight decrease in pigment levels was observed immediately after the herbicides' application, followed by stabilization. In contrast, the introduction of the herbicide Concur c.s. led to a decrease in photosynthetic activity and a reduction in pigment levels. This suggests that the active ingredient metribuzin lacks complete selectivity for soybeans, implying that there is a potential for crop suppression when it is applied.

Prospects for further research consist in studying the use of tank mixtures and compositions for applying soil herbicides with post-emergence herbicides in soybean crops.

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CONFLICT OF INTEREST

None.

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Гербіцидний вплив на агроценоз сої та її фотосинтетичну активність у Західному Лісостепу України

Іван Антонович Шувар

Доктор сільськогосподарських наук, професор
Львівський національний університет природокористування
80381, вул. В. Великого, 1, м. Дубляни, Львівська область, Україна
https://orcid.org/0000-0002-4149-1761

Ганна Михайлівна Корпіта

Кандидат сільськогосподарських наук, доцент
Львівський національний університет природокористування
80381, вул. В. Великого, 1, м. Дубляни, Львівська область, Україна
https://orcid.org/0000-0002-0908-0129

Анотація. Застосування гербіцидів може суттєво впливати на процеси фотосинтезу рослин, оскільки призводить до пригнічення утворення пігментів, погіршує транспорт електронів у дихальному ланцюзі та фіксацію вуглецю. Мета дослідження – визначити вплив застосування гербіцидів на забур'яненість та фотосинтетичну активність сої. На основі польового дослідження в умовах Навчально-наукового центру Львівського національного університету природокористування встановлено залежність урожайності сої від рівня забур'яненості посівів культури. Найбільшу врожайність сої – 29,0 т/га було отримано при застосуванні гербіциду Primekstra TZ Gold 500 SC c.s. (4,5 л/га), найменшу – 27,3 т/га серед варіантів досліду було отримано при післясходовому застосуванні гербіциду Pulsar s.c. (1 л/га). Застосування гербіциду Primekstra TZ Gold 500 SC c.s. не впливало на інтенсивність фотосинтезу, а кількість пігментів у листках сої достовірно не відрізнялася від показника на контролі. Застосування препаратів Kommand k.e. та Pulsar s.c. призводило до незначного зниження кількості пігментів у перші дні після внесення та поступової їх стабілізації. Застосування гербіциду Concur c.s. призводило до послаблення фотосинтетичної активності та зменшення кількості пігментів. Це свідчить про те, що діюча речовина метрибузин не є абсолютно селективною щодо впливу на рослини сої, тобто в разі її застосування існує ймовірність пригнічення культури. Практична значимість одержаних результатів полягає у розкритті можливостей вибору ефективних гербіцидів з підвищеною селективною фітотоксичністю, які забезпечують ефективний контроль чисельності бур'янів за мінімальної ймовірності негативного впливу гербіцидів на агроценоз сої

Ключові слова: соя; пігменти; діюча речовина; фотосинтез; бур'яни; продуктивність