Resistance of sunflower (Helianthus annuus L.) to oxyfluorfen when applied during the growing season

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Abstract. The article reflects the results of studies carried out in the period from 2017 to 2019 in the dry steppe zone of the Russian Federation to assess the resistance of sunflower and the effectiveness of weed control when using oxyfluorfen before sowing and during the growing season of the crop in various doses and tank mixtures. The dynamics of weediness of sunflower crops according to the growing season of the crop and the timing of the use of herbicides and their tank mixtures has been established. The data of accounting for the increase in leaf area, as well as determining the photosynthetic potential of crops and the net productivity of photosynthesis when using herbicides before sowing and during the growing season of sunflower in different doses and tank mixtures are presented. Indicators of sunflower productivity and quality of seeds were determined for the studied schemes of herbicide application. The data obtained from the economic and energy assessment of the effectiveness of the use of oxyfluorfen on sunflower in terms of crop vegetation are analyzed.

1. Introduction

Ensuring sustainable production of sunflower is associated with the search for new technological solutions. One of such solutions is the development of effective methods for protecting crops from weeds during the growing season. Along with mechanical measures, the application of herbicides against weeds is now an integral part of an integrated crop protection system.

The existing system of chemical protection of sunflower is based on the use of herbicides according to the following schemes:

- Application of soil herbicides before sowing against annual and perennial monocotyledonous and some annual dicotyledonous weeds;
- Application of general exterminating herbicides in the spring before sowing, or immediately after sowing;
- Application of graminicides for sunflower vegetation against perennial and annual monocotyledonous weeds.

In modern technologies of sunflower cultivation there is no effective chemical protection of crops against dicotyledonous weeds during the growing season of the crop, with the exception of systems providing for the cultivation of hybrids that are resistant to herbicides based on imazamox, imazapyr or tribenuron-methyl [1-2].
The selection of sunflower for resistance to imazamox and imazapyr is based on the discovered natural resistance of wild forms of sunflower, which is a limitation of the use of herbicides based on them for the majority of cultivated sunflower hybrids [3-4].

The issues of manifestation of signs of resistance of sunflower to herbicides are widely described in the world scientific literature [5-7]. At the same time, the effect of oxyfluorfen's per-emergence application on the growth and development of sunflower, as well as the effectiveness of control of dicotyledonous weeds, has not been studied enough.

Soil herbicides directly affect the physiological processes of cultivated plants. Thus, in the vegetation experiment conducted by E. Nadasy, M. Nadasy, and V. Nagy [8], the use of oxyfluorfen led to a decrease in the wet and dry mass of sunflower seedlings, which is associated with a violation of the processes of transformation of nutrients in the soil solution and a violation of the mineral nutrition of plants.

In field experiments conducted by E. Pannacci, F. Graziani, and G. Covarelli [9] in central Italy on sunflower to assess the effectiveness of weed control and the selectivity of herbicides in relation to the crop, it was found that when the oxyfluorfen-based herbicide was applied regularly, signs of phytotoxicity without a significant decrease in crop yield.

According to a field experiment conducted by A.N. Giri, R.H. Bhosle and O.G. Lokhande [10] in Parbhani district (India), evaluating the effectiveness of methods of weed control on sunflower, found that high economic efficiency was obtained using oxyfluorfen.

In the conditions of Central Bohemia (Czech Republic), studies were carried out to study the efficacy and selectivity of pre-emergence herbicides to sunflower containing the active substances fluorochloridone, linuron and oxyfluorfen [11]. About 25-35% of herbicide residues were found in the soil 60 days after application, with the exception of oxyfluorfen, the residual concentration of which was 60%. Oxyfluorfen showed high mobility and caused the greatest degree of damage to sunflower, especially in conditions of sufficient moisture supply.

2. Materials and methods
The studies were conducted from 2017 to 2019, at the Don State Agrarian University.

The object of the research was the sunflower culture. The subject of the research is the assessment of the resistance of sunflower to the use of herbicides based on oxyfluorfen during the growing season of the crop.

In terms of natural and climatic zoning, the research site belongs to the steppe zone of the Russian Federation. The climate is characterized by unstable humidity, moderately hot, continental. Average long-term precipitation is 495 mm. The distribution of precipitation throughout the year is uneven. The soil cover of the experimental site is represented by ordinary carbonate heavy loamy chernozem.

The experimental scheme is presented in Table 1. The experiments were repeated three times. The area of the accounting plot is 80 m². The experiment was laid for sunflower in the link of crop rotation: corn for grain - spring barley - sunflower.

The studies were carried out according to standard methods. The laying of field experiments was carried out in accordance with the requirements of the experimental methodology. Determination of weediness of crops by a quantitative method. Structural and quality parameters of seeds (moisture content of seeds according to GOST-12041-82, weight of 1000 seeds according to GOST-10802-76). Biological seed yield - by calculation method. Phenological observations in accordance with the methodology of state variety testing. To determine the leaf area, a die-cutting method was used. The net productivity of photosynthesis was determined by the formula (1):

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CHPF = \frac{V_2 - V_1}{FP}
\]

Where: CHPF - net productivity of photosynthesis, g/m² day; V₂ and V₁ - dry weight of plants per unit area at the end and beginning of the period, g; FP - photosynthetic potential, thousand m² day/ha.
Statistical analysis of research results by analysis of variance. Evaluation of the effectiveness of research results by methods of economic and energy analysis.

Characteristics of the herbicides studied in the experiment:

- **Goal 2E, KE.** Active ingredient: oxyfluorfen, 240 g / l. Chemical class: diphenyl ether. Soil herbicide against annual dicotyledonous and some monocotyledonous weeds. Provides long lasting protective effect.
- **Zonator, BP.** Active ingredient: imazamox 40 g / l. Chemical Class: Imidazolinones. Postemergence herbicide against annual grasses and dicotyledonous weeds on sunflower hybrids resistant to imidazolinones.
- **Tornado 500, BP.** Active ingredient: glyphosate 500 g / l. Chemical class: organophosphorus compounds. Universal herbicide of continuous action. Provides complete destruction of almost all types of annual and perennial dicotyledonous and monocotyledonous weeds.

In the experiment, a hybrid of sunflower Solarni KS (originator: CAUSSADE SEMENCES SA), resistant to imazamox, was sown.

3. Results

Analysis of the structure of the weed component in sunflower crops showed that dicotyledonous juvenile weeds prevailed in the agrophytocenosis. During the period of two pairs of true leaves, the highest occurrence was noted for Setaria viridis L., Sinapis arvensis L., Chenopodium album L., among perennial weeds - Convolvulus arvensis L. and Sonchus arvensis L. By the period of four pairs of true leaves, the following appeared in crops: Polygonum convolvulus L., Ambrosia artemisiifolia L. and Amaranthus retroflexus L. By the period of budding, the species composition of weeds in crops did not change. Over the years of research, the structure of the weed component has not changed significantly since the experiments were carried out within a homogeneous agricultural landscape.

The highest efficiency of weed death in the phase of two pairs of true sunflower leaves is noted in the variant of the experiment using a tank mixture of herbicides Tornado 500 and Goal 2E. In the phase of four pairs of true sunflower leaves, the greatest efficiency of weed death is observed in variants with treatment with Goal 2E and Zonator herbicides for the growing season of the crop. The number of weeds in these variants of the experiment is three times lower compared to the control, and by 50% compared to the treatment with Goal 2E herbicide before sowing. The high efficiency of weed control in variants with the use of oxyfluorfen was preserved until the stage of flowering baskets. In the experiment, there was no increase in the level of weed death when treating sunflower crops with Goal 2E herbicide at a rate of 0.8 l / ha, compared with the application rate of 1.1 / ha.

Observations have shown that the effectiveness in suppressing weeds when treated with a herbicide based on oxyfluorfen during the growing season of the crop is higher than with a herbicide containing the active ingredient imazamox. The longer protective effect of using oxyfluorfen is explained by the soil action of the drug due to the formation of a protective shield.

Studies have shown that the smallest values of the increase in leaf area during the period of basket formation were noted in the variant without the use of herbicides (11.4 ... 12.1 thousand m2 / ha), which is associated with interspecific competition in agrophytocenosis due to an increase in weediness of sunflower crops. A low growth rate of leaf area was also observed in the variants with the repeated application of the Goal 2E herbicide at doses of 1.0 and 0.8 l / ha. This fact is explained by the death of the first pair of true sunflower leaves and a slight lag in growth of plants. The highest growth rate of the leaf surface during the period of basket formation was observed in the variants with the use of herbicides before sowing the crop. By the flowering period, the growth rates of the leaf surface after treatment with the Goal 2E herbicide increased during the sunflower vegetation and reached the values observed in the variant with the Zonator.

During the period of seed filling in the variants of the experiment with the treatment with Goal 2E and Zonator herbicides, the intensity of the growth of the leaf surface during vegetation was higher.
than in the variant without the use of herbicides, as well as in the variants with the introduction of herbicides before sowing. This trend continued until the phase of full ripeness of the sunflower.

The data presented in table 1 indicate that the highest value of the photosynthetic potential (FP) of sunflower crops is observed in the variants with treatment with herbicide based on oxyfluorfen during the growing season of the crop (1664 thousand m$^2$ day / ha). In the variant of the experiment with the treatment with herbicide based on imazamox, the PP value was slightly lower and amounted to 1594 thousand m$^2$ day / ha, and in the variants with the herbicide application before sowing, the PP value was in the range 1507 ... 1606 thousand m$^2$ day / ha. The lowest PP was observed in the variant without the use of herbicides - 1190 thousand m$^2$ day / ha.

**Table 1.** Photosynthetic potential value (average for 2017-2019).

| Experience Option | Duration of the seedling-ripening interphase period, days | Maximum leaf area, thousand m$^2$/ha | Photosynthetic potential, thousand m$^2$ day/ha |
|-------------------|----------------------------------------------------------|-------------------------------------|-----------------------------------------------|
| No herbicides (control) | 124 | 19.2 | 1190 |
| Tornado 500 (1.5 l / ha) + Goal 2E (1 l / ha) before sowing the crop | 129 | 24.6 | 1587 |
| Goal 2E (1 l / ha) before sowing | 128 | 25.1 | 1606 |
| Goal 2E (1 l / ha) in the phase of two pairs of leaves | 129 | 25.8 | 1664 |
| Goal 2E (0.8 l / ha) in the phase of two pairs of leaves | 130 | 25.6 | 1664 |
| Zonator (1 l / ha) in the phase of two pairs of leaves | 126 | 25.3 | 1594 |

The net productivity of photosynthesis (NPF) characterizes the intensity of photosynthesis of crops. In the initial growing season, the NPF is higher than in the subsequent one, since during this period the plants do not shade each other. With an increase in the leaf area, the NPF begins to decrease due to the mutual shading of the lower leaves, and with a high infestation of crops - by weeds. The NPF value depends on the phytosanitary state of crops, the growing season, soil and weather conditions, and other factors.

The minimum NPF was observed in the variant without herbicide treatment (7.14 g / m$^2$). In variants with the use of herbicides before sowing, this indicator was 7.81 ... 7.92 g / m$^2$ day (table 2). The highest rate of PPF was observed in variants with herbicide treatment based on oxyfluorfen and imazamox during the growing season of the crop (8.40 ... 8.54 g / m$^2$ day).

**Table 2.** Net productivity of photosynthesis, g / m$^2$ day.

| Experience Option | 2017 | 2018 | 2019 | Average |
|-------------------|------|------|------|---------|
| No herbicides (control) | 7.34 | 7.22 | 6.86 | 7.14 |
| Tornado 500 (1.5 l / ha) + Goal 2E (1 l / ha) before sowing the crop | 8.12 | 7.99 | 7.59 | 7.90 |
| Goal 2E (1 l / ha) before sowing | 8.14 | 8.01 | 7.61 | 7.92 |
| Goal 2E (1 l / ha) in the phase of two pairs of leaves | 8.63 | 8.49 | 8.07 | 8.40 |
| Goal 2E (0.8 l / ha) in the phase of two pairs of leaves | 8.78 | 8.63 | 8.20 | 8.54 |
| Zonator (1 l / ha) in the phase of two pairs of leaves | 8.71 | 8.56 | 8.13 | 8.47 |
| No herbicides (control) | 8.03 | 7.89 | 7.50 | 7.81 |
Despite the death of the first pair of true leaves, in the variants with treatment with oxyfluorfen during the growing season of the crop, the PPF was the highest, since by the period of formation of the basket the lower leaves are shaded and do not play a significant role in the accumulation of dry matter.

The data on the yield of sunflower seeds presented in figure 1 indicate that, on average, over the years of research, the lowest level of sunflower productivity was obtained in the variant without the use of herbicides (2.15 t / ha). The greatest statistically significant increase in seed yield, compared to the control, is observed in the variants of the experiment with the treatment of sunflower crops in the phase of two true leaves with herbicides containing the active substance oxyfluorfen and imazamox (0.82 ... 0.85 t / ha).

![Sunflower seed yield](image)

**Figure 1.** Sunflower seed yield. (2017 NDS0.5 = 0.31 t / ha; 2018 NDS0.5 = 0.33 t / ha; 2019 NDS0.5 = 0.35 t / ha).

The largest collection of oil was obtained during the per-emergence treatment with Goal 2E at doses of 0.8 and 1.01 / ha and Zonator (1.20 ... 1.24 t / ha). On average, over the years of research, the smallest oil collection was obtained in variants without the use of herbicides - 0.81 ... 1.03 t / ha. In variants with the introduction of herbicides before sowing, the average oil yield was in the range of 1.00 ... 1.06 t / ha.

Evaluation of the economic efficiency of the research results made it possible to establish that the lowest cost of sunflower cultivation in the experiment was provided by the technology with herbicide treatment Goal 2E and Zonator for crop vegetation - 8.9 ... 9.2 thousand rubles. The highest level of profitability of sunflower production was observed during the emerging treatment with herbicides containing the active ingredient oxyfluorfen and imazamox (89.4 ... 97.6%), and the lowest (61.5%) in the option without the use of herbicides and with the introduction of a tank mixture of herbicides Tornado 500 and Goal 2E before sowing.

The highest consumption of total energy in the experiment was noted in the variant using a tank mixture of herbicides Tornado 500 and Goal 2E (10100 MJ / ha). In variants with treatment with herbicides for sunflower seedlings, the total energy consumption was 9984 ... 9994 MJ / ha. The smallest consumption of total energy is observed in the control, without herbicide treatment (9378 MJ / ha).
The highest coefficient of energy efficiency was obtained in the case of repeated treatment with herbicides based on oxyfluorfen and imazamox (5.73 ... 5.80), the lowest - in the variant without the use of herbicides (4.42).

4. Discussion
The experimentally observed phytotoxic effect of oxyfluorfen on sunflower in the phase of two pairs of true leaves, which led to the death of the first leaves of the culture treated with herbicides, did not lead to complete death of the plants. The data of accounting for the increase in leaf area, as well as the determination of the photosynthetic potential of crops and the net productivity of photosynthesis, indicate that by the period of flowering of baskets, the assimilation surface of plants has fully recovered and did not limit the rate of accumulation of dry matter.

Currently used herbicides based on oxyfluorfen are recommended as a soil action and are applied before crop sowing, providing a long-lasting protective shield in the initial period of crop development. As shown by the results of weed counting, due to this property, the use of oxyfluorfen in the phase of two pairs of true leaves provides protection from weeds until the stage of flowering baskets.

Despite the manifestation of signs of phytotoxicity, the use of oxyfluorfen during the growing season of sunflower provides a higher seed yield compared to the options for using herbicides before sowing, as well as without using herbicides, due to the long-term protective effect. Analysis of the data on the economic and energy efficiency of crop cultivation indicates a similar level of efficiency of the use of oxyfluorfen and imazamox, however, the use of imazamox is limited by the choice of a hybrid composition of the crop.

5. Conclusion
The use of oxyfluorfen during the growing season of sunflower has a phytotoxic effect, which manifests itself in the form of damage and death of the first two true leaves of the culture, however, the plants are completely restored, which does not significantly affect the productivity of the crop. The use of oxyfluorfen during the growing season of sunflower provides a longer protective effect due to the soil action and can be used on any varieties and hybrids.

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