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SCIENTIFIC CONSIDERATIONS ON THE IMPROVEMENT OF THE RANGE OF HERBICIDES FOR THE PROTECTION OF SUNFLOWER CROPS

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ABSTRACT

We have determined the infestation patterns of the sunflower crops in different soil and climate zones, and defined the factors of the herbicide application to the plantations. This article provides the results of the investigation of biological effectiveness and the development of the regulations on the use of new agents for the improvement and expansion of the range of herbicides for the protection of sunflower crops.

Keywords: range of pesticides, herbicides, sunflower, weeds, biological effectiveness of the agents, regulations of use

INTRODUCTION

Sunflower cultivation in almost every region of the Russian Federation requires protection of the crops from a wide range of weeds. The phytosanitary status of the plantations is quite complicated, as though the weeds are relatively consistent, as compared to all noxious organisms in general, the problems are often exacerbated due to the place of sunflower in the rotation of crops that contradicts the scientific principles of this system, to the increasing proportion of sunflower in the cropping plan, and to the economic environment that attenuates the agrotechnical pressure on weeds as a result of lower number and intensity of soil treatments.

Hence, application of chemicals that decrease the weed pressure on the crops is currently an essential plant of any sunflower cultivation technology [1].

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It should be noted that, ideally, this approach is not only designed to preserve a certain part of crop yield, resulting in higher production of valuable oleaginous materials; application of herbicides, and especially combined treatments, provides certain decrease in the levels of infestation of future crops.

All the history of development and improvement of the range of herbicides has been strongly influenced by the existence of soil graminicides with pre-sowing and/or pre-emergence application and detection in the crops.Lately, the treatments for the protection of sunflower crops from weeds have been intensively upgraded due to the implementation of the unparalleled combination of herbicides and resistant hybrids in an integral system ("CLEARFIELD"). Development of the chemical agents is important for this process, as current zonal technologies of crop cultivation are more and more often linked to the short-period crop rotation systems.

Considering the current status of the approaches to sunflower protection from weeds, this study was focused on the improvement of the range of herbicides that are allowed for use in the sunflower plantations, and development of the foundations for the regulations on the use of novel modern treatments that have not been applied to the sunflower crops before. The scope of the study mostly included the agents, selected on the basis of the development of new herbicides and the fact that, in most regions, large amounts of annual weeds are detected every year in the sunflower crops.The aim of the study was to achieve the maximal biological effectiveness of the treatments and to prevent the adverse consequences of the pesticide use [2].

METHODS

The scope of the study included modern herbicides with good potential for implementation in the system of the sunflower crops protection. Considering the previously discussed issues, we assessed the biological effectiveness of several new herbicides in different conditions of three soil and climate zones of the country.The following agents, included in the "National catalogue of pesticides and agrochemicals, certified for use in the Russian Federation", were used as reference for the experiments, according to the legal guidelines: Dual Gold EC (*960 g/L S-metolachlor*); Stomp EC (*330 g/L pendimethalin*); Gardo Gold SC (*312.5 g/L S-metolachlor + 187.5 g/L terbuthylazine*); Euro-Lightning WSC (*33 g/L imazamox + 15 g/L imazapyr*); in the experiments up to 2013 inclusive (until the ban of the active ingredient *acetochlor*) – Harness EC (900 g/L).Special attention was paid to the field microplot trials (25-50 m^2), conducted in compliance with the existing practices [3,4]. The effects of each agent have been studied for at least two years, in three different soil and climate zones in parallel, on the seeds and crops of either varieties adapted to specific conditions (Irtysh, Yenisei, Yubileinyi 60, Flagman) or sunflower hybrids (Tristan, NK Neoma, NK Fortimi, ES Florimis) resistant to specific active ingredients (tribenuron-methyl) or chemical classes (imidazolinones).

RESULTS AND DISCUSSION

The results of the phytosanitary monitoring preceding and complementing the studies on the biological effectiveness and safety of the new herbicides show that currently the sunflower crops are to a significant degree infested over the whole cropping area. Mean density of weeds in the fields where the experiments have been conducted was over 200 plants/m^2 in the Altai Krai, up to 150 plants/m^2 in the central European part of the country, and close to 100 plants/m^2 in the southern territories (Table 1).

Table 1. Levels of infestation of the sunflower crops in different regions of the Russian Federation

Region	Average density (plants/m^2) during the treatment or the first measurement				Percentage of dicotyledon weeds in the complex			
	2012	2013	2014	2015	2012	2013	2014	2015
Altai Krai *(I soil and climate zone)*	182	210	236	239	16.8	17.7	24.0	14.1
Tambov Oblast*(IIzone)*	127	153	104	152	77.4	35.6	52.9	43.8
Krasnodar Krai*(IIzone)*	101	96	85	58	40.1	41.4	44.5	62.9
Astrakhan Oblast*(III zone)*	109	157	78	82	41.4	38.6	57.6	58.5

The weed complex was strongly dominated by the annual graminaceous weeds only in the first soil and climate zone. In other regions, the ratios were more balanced (the proportion of dicotyledons ranged from 47.9 to 52.4% on average), with seasonal fluctuations towards either graminaceous plants or dicotyledons depending on the weather factors (Table 1). Hence, the sunflower farm ecosystem generally has mixed infestation.According to the measurements, annual and biennial species are clearly more abundant, accounting for over 90% of the plant numbers.

At the beginning of the vegetative period, approximately 30 weed species of 19-23 families emerge in the cultivated crops and form the basis of the species composition, which has been also confirmed by previous research on this topic [5]. Against this background, the classical complex comprises abundant annual graminaceous plants, including *cockspur grass (Echinochloa crusgalli (L.) Beauv)* and/or *yellow foxtail (Setaria pumila (Poir.) Schult.)*; annual dicotyledons, including *red-root amaranth (Amaranthus retroflexus* L.), *lamb's quarters (Chenopodium album* L.*)*, *black bindweed (Fallopia convolvulus (L.) A Love),*and 2-3 more species of *knotweed (Polygonum spp.), hemp-nettle (Galeopsis spp.), common cocklebur (Xanthium strumarium L.)*and perennial broadleaf weeds, the most common of which are thistles *(Cirsium arvense and C. setorum)*and field bindweed (*Convolvulus arvensis* L.).

At the same time, we observed certain regional differences in the development of the weed complexes in the sunflower farm ecosystem. Our results show almost constant presence of*proso millet* (*Panicum miliaceum subsp. ruderale (Kitag.) Tzvel.*) and *ball mustard* (*Neslia paniculata (L.) Desv.*) in the first soil and climate zone, particularly in the Altai Krai; *annual hedge-nettle* (*Stachys annua L.*), *field mustard* (*Sinapis arvensis L.*) and*hemp-nettle* (*Galeopsis tetrahit L.*) in the Central Chernozem Region, the second zone, *common ragweed* (*Ambrosia artemisiifolia L.*) in the Krasnodar Krai and Rostov Oblast, the second zone; in Astrakhan Oblast, located within the third zone, such species as*black nightshade* (*Solanum nigrum L.*), *velvetleaf* (*Abutilon theophrasti Medik.*), *common purslane* (*Portulaca oleracea L.*), and*saltwort* (*Salsola pestifera Nels.*) are quite common.

Considering these findings and clear concurrent presence of both dicotyledon and graminaceous weeds in all crops, an essential aspect of tactical choice of the treatment is susceptibility of these plants to the same active ingredients. A confounding factor influencing the choice of the agents is (particularly lately) the varietal response of the cultivated crops, as currently progressive development of the herbicide range is impacted by the emergence and expansion of the hybrids that are, either generally or at the initial stages of development, resistant to the active chemical agents of specific groups (sulfonylureas, imidazolinones).In the course of development of this product line, new active ingredients that have never been applied to cultivated crops also emerged; recent studies, for instance, are focused on the use of *ethametsulfuron-methyl.*

These issues, combined with the regional climate factors, further substantiate the need for the improvement of the herbicide range and, to a certain extent, detailed diversification of the herbicide choice and application guidelines.Within this group of pesticides, the modern basis for the strategic development with regard to sunflower reflects, on the one hand, the priority for the treatments performed at the beginning of the crop vegetation with a view to prolonged protection until the plants reach the active growth stage, and, on the other hand, development of the combinations of two active ingredients and use of surfactants.Two latter constituents provide an opportunity to target a wider range of weeds and to mitigate the risks of the emerging tolerance to individual active agents [6].

Altogether, it is quite natural that current situation had to have impact on the development and adjustment of the range of herbicides allowed for use in sunflower. As a result, while ten years ago the list of agents for sunflower crops comprised 12 drugs, 4 of which were purely anti-graminaceous, in 2017 the number of registered agents of the latter category has reached 41, with the full range including 93 herbicides – over 12% of the total number of drugs (in 2017, the "National catalogue…" lists 738 herbicides). Against the background of a higher number of drugs for the pre-sowing and pre-emergence treatment (up to 38 items), there has been a significant increase in the range of the agents suitable for use at the early stages of the sunflower development (from 2-4 to 6-8 true leaves).This set of drugs, that has already been approved for use in the "herbicide + resistant sunflower variety" complex, comprises 14 agents, including the products of Russian companies, but wide-range import substitution is clearly impeded by the lack of the home-developed hybrids.

The potential and demand for the use of the discussed system, based on the application of the wide-range herbicides specifically at the beginning of the crop vegetative period, for the protection of sunflower crops are proved by the fact that 4 out of 7 recently registered drugs fall into this category (Table 2).

Table 2. Elements of the improvement of the range of drugs for the protection of sunflower crops from weeds

Chemical class	Name of the drug (active ingredient)	Target species
Chloroacetamides	**Difilain, EC** *(960 g/LS-metolachlor)*	annual graminaceous and certain dicotyledon weeds
Dinitroanilines	**Gaitan, EC** *(330 g/Lpendimethalin)*	annual graminaceous and dicotyledon weeds
Chloroacetamides + triazines	**Kiborg, SC** *(312.5 g/LS-metolachlor +187.5 g/Lterbuthylazine)*	annual graminaceous and dicotyledon weeds
Imidazolinones	**Paradoks, WSC** *(120 g/Limazamox)*	annual graminaceous and dicotyledon weeds
Aryloxyphenoxypropionates + imidazolinones	**Germes, OD** *(50 g/Lquizalofop-p-ethyl + 38 g/Limazamox)*	annual and certain perennial dicotyledons and graminaceous weeds
Imidazolinones	**Kaptora, WSC** *(33 g/Limazamox + 15 L/hectareimazapyr)*	annual graminaceous and dicotyledon weeds
Sulfonylureas	**Salsa, WP** *(750 g/kgethametsulfuronmethyl)*	annual, incl. crucifers, and certain perennial dicotyledon weeds

General conclusion from the experimental results shows that implementation of this approach might increase effectiveness of protection against annual dicotelydon and graminaceous weeds in the sunflower crops by 8-15%. Apart from that, application of the tribenuron-methyl- and ethametsulfuronmethyl-based drugs can suppress the perennial weeds, leading to more than 70% decrease in numbers and 90% decrease in the plant mass [7].

Based on the results of the assessment of biological effectiveness and safety for the crops, as well as of the development of the regulations for use of the drug combinations, some of the latter (Table 2) have already been formally approved for use at sunflower plantations in the

Russian Federation [8]. Crop treatment with any of these formulations almost always had 80% and higher effeciency (Table 3).

Table 3. Biological effectiveness of modern herbicides for the protection of sunflower crops

Herbicide	Rate of application, L/hectare, kg/hectare	Decrease in the number of weeds		Decrease in the mass of weeds, %	
		on average %	compared to the reference, %	annual dicotyledons	annual graminaceous
Difilain, EC *(960 g/L)*	1.3 - 1.6	82.5	0	64.1	91.5
Gaitan, EC *(330 g/L)*	3.0 - 6.0	84.3	+ 1.0	91.8	78.3
Kiborg, SC *(312.5 + 187.5 g/L)*	3.0 - 4.0	84.1	+ 1.3	85.0	92.0
Paradoks, WSC *(120 g/L)*	0.3 - 0.4	81.2	- 8.1	80.9	81.3
Germes, OD *(50 + 38 g/L)*	0.9 - 1.0	85.3	- 1.2	82.4	85.8
Kaptora, WSC *(33 + 15 L/hectare)*	1.0 - 1.2	85.8	+ 4.7	89.3	91.2
Salsa, WP*(750 g/kg)* + **Trend 90, L**	0.02 - 0.025 + 0.2	91.9	+ 5.9	94.3	-

The effectiveness of the tested herbicides was in most cases similar to or higher than the effectiveness of conventionally applied treatments.

As for the drugs containing imidazolinones, Kaptora WSC was the only one of the new set of formulations consistently showing stronger effects than Euro-Lightning WSC, which has been used as reference. Against this background, we observed rather uniform susceptibility to the herbicides of this class in both groups of annual weeds, according to the decrease in the plant mass. In the nearest time, one could expect emergence of a wider range of herbicides used in the cultivated crops, primarily due to the imazamox-based drugs.This pattern of development reflects the changes in the content of the active ingredient. Experimental studies have shown the most pronounced effect in case if the applied amounts of drugs were equivalent to 45 g/hectare of this active agent. Considering the toxic load on the farm ecosystem, it should be noted that transition to this level will clearly decrease the burden.

Regarding the suppression of dicotyledon weeds, the best results were observed after the crop treatment with Salsa WP combined with Trend 90 L surfactant.Gaitan EC, the pre-emergence herbicide, had, in general, similar effect on this systematic group.At the same time, the assessment of the decrease in mass of each of two annual weed groups has shown that two other drugs, containing *S-metolachlor,* preeminently (17% an 7% more, with the average values of approximately 92%) affect graminaceous annual plants (Table 3).

Apart from the previously discussed aspects, the species-specific response of the weeds to the exposure to the herbicides is also worth noting. More detailed analysis of the experimental results allows one to define the following species as weakly to moderately tolerant to Difilain EC: *black bindweed,black nightshade*, *velvetleaf* and*common ragweed*; to Gaitana EC - *cockspur grass, ball mustard, black bindweed, black nightshade and common ragweed*; to Kiborg SC–*European stickseed, black nightshade, velvetleafandcommon ragweed*; to Paradoks WSC - *cockspur grass, velvetleaf and common purslane*; to Germes OD - *black nightshade*; to Salsa WP - *lamb's quarters* and *creeping thistle*.

Application rates constitute an important part of the regulations for herbicides. In most cases, the best results in Astrakhan Oblast have been achieved when the drugs were applied at the upper threshold rate of the established regulations (Table 3). Hence, application of each of 7 herbicides, currently approved for use in sunflower crops, guaranteed the most beneficial effects, in terms of reduction of the numbers and mass of weeds, as well as higher proportion of preserved harvest, within the maximum permitted range particularly in the third soil and climate zone.

Another important argument in favor of using the examined drugs is their safety for the crops. Certain negative effects were observed only after the treatment with the combined herbicide Kaptora WSC. Application of this drug in the second and the third soil and climate zones during the seasons with higher air temperature was accompanied by the emergence of yellow spots on the leaves. Later, these discolorations leveled off, and no significant impact on the growth and development of the sunflower plants was observed. However, it should be noted that this effect was severely exacerbated, resulting even in the damage of the apical meristem, if the application rate was raised up to 2.4 L/hectare or there was an overlap of treatments.

Special attention should be paid to the results of the assessment of the economic efficiency of treatment with modern herbicides (Table 4).

Table 4. Economic efficiency of the herbicide treatments of the sunflower crops

Herbicide	Minimal preserved harvest, average values, %			
	Altai Krai	Tambov Oblast	Krasnodar Krai	Astrakhan Oblast
Difilain, EC *(960 g/L)*	40.5	-	22.7	12.0
Gaitan, EC *(330 g/L)*	40.3	-	15.1	21.4
Kiborg, SC *(312.5 + 187.5 g/L)*	51.8	-	17.1	9.4
Paradoks, WSC *(120 g/L)*	38.3	22.4	-	23.5
Germes, OD *(50 + 38 g/L)*	43.0	23.9	-	22.1
Kaptora, WSC *(33 + 15 L/hectare)*	48.2	24.3	-	17.0
Salsa, WP *(750 g/kg)* + **Trend 90, L**	54.4	16.8	14.0	-
Average for the region	45.8	23.5	17.2	17.6

The results shown in the table confirm the positive economic effects on the sunflower crops, that are clearly visible at almost any level of productivity. In 29 conducted experiments (in 19 of them the crop productivity was within the ranges of 8-15 and 10 - 15-25 centner/hectare), we observed higher yield, statistically significant in 26 cases. The most pronounced response of the crops, resulting in the proportion of preserved harvest ranging from 38 to 54% over the period of studies, was found in the Altai Krai, the region belonging to the first soil and climate zone. However, it should be noted that the baseline crop productivity in this case was within the range of 8-12 centner/hectare. In case of higher productivity, the observed changes were usually up to 20%.

Against this background, improvement of the range of herbicides for the sunflower crops protection is constantly complemented with the development and, lately, validation on a case-by-case basis of the techniques for the analysis of the residual content of pesticides in the harvest. In case of herbicides, novel approaches are regulated by high-technology guidelines "Detection of the residual content of *cycloxydim* in water, soil, tops and roots of sugar beet, potato tubers, peas, *sunflower seeds,* canola seeds, soybeans, and vegetable oil with high-performance liquid chromatography" (Stratos Ultra EC formulation) and "Detection of the residual content of *flucarbazone-sodium* in *sunflower seeds and oil* with high-performance liquid chromatography" (Everest EC formulation), that have already been approved by the Federal Service for the Surveillance in the Sphere of Consumer's Rights Protection and Public Welfare (Methodical Guidelines 4.1.3236-14 and 4.1.3405-16) as the official innovative methods for the detection of the residual content of pesticides in agricultural products, soil, and water bodies [9].

Hence, the studies conducted in Astrakhan, Belgorod and Tambov Oblast, the Volga Region, the Altai and Krasnodar Krai of the Russian Federation allowed us to make an overview of the phytosanitary condition of the sunflower crops in terms of the presence of weeds, to define specific regional features of the composition of this part of the farm ecosystems, as well as to develop the regulations for application of the new herbicides that have not been previously used in this type of crops.

The results of our experiments, of the assessment of the direct action and consequences of the drug application have substantiated development and certain improvement of the range of pesticides for the protection of sunflower crops from weeds. Motivated regulations for use of each of the examined herbicides provided consistent biological and economic effects, which, in turn, served as the rationale for including each of these drugs in the list of treatments approved for use in the Russian Federation.

In general, the strategy of development and improvement of the range of herbicides for the protection of sunflower crops in the Russian Federation will, in the nearest future, be clearly based on the combinations of the existing active ingredients and will be further directed to the use of the herbicides together with the resistant hybrids.

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