AGRICULTURAL SCIENCE AND TECHNOLOGY, VOL. 16, No 4 pp 74-81, 2024
Published by Faculty of Agriculture, Trakia University, Bulgaria
ISSN 1313-8820 (print)
ISSN 1314-412X (online)
http://www.agriscitech.eu
DOI: 10.15547/ast.2024.04.042

Selectivity and stability of the herbicidal product Envoke applied during the vegetation of cotton (*Gossypium hirsutum* L.)

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(Manuscript received 2 June 2023; accepted for publication 23 June 2024)

Abstract. *The research was conducted during the period 2020-2022 in the experimental field of the Field Crops Institute – Chirpan, Bulgaria. In a three-factor field experiment, the effect of the vegetation-applied herbicide Envoke, containing 75% trifloxysulforon-sodium, was tested on two cotton cultivars. Factor A includes the three years of the study. Factor B includes the cotton cultivars Chirpan-539 and Helius. Factor C includes the herbicide Envoke, applied in 3 rates – 10 g ha^{-1}, 15 g ha^{-1}, 20 g ha^{-1}, once and two times during the 4-5 leaf and budding stages of cotton. The aim of the trial was to study the selectivity and stability of the effects of the three different rates of the herbicide Envoke on cotton under different weather conditions. It has been found that the vegetation-applied herbicide Envoke, applied in the three rates, once and two times during the 4-5 leaf and budding stages of cotton, does not have a phytotoxic effect on the crop and is selective to the two cultivars - Chirpan-539 and Helius. The highest yields in both cotton cultivars were obtained with the two-time application of the herbicide Envoke during the 4-5 leaf and budding stages. Technologically, the most valuable are all variants with the herbicide Envoke for the cultivar Chirpan-539 and the variants with the herbicide Envoke in rates of 15 g ha^{-1} and 20 g ha^{-1} for the cultivar Helius. These variants combine high yield values and high stability of this indicator in different years. The untreated controls in the two cotton cultivars were the only ones that received negative evaluations. This is due to the high number of weeds and sunflower volunteers.*

Keywords: cotton, weeds, herbicides, selectivity, stability

Introduction

A key component in successful cotton production is the effective weed management. The cotton plant is not particularly competitive with many weed species, especially early in the season (Berger et al., 2015; Jabran, 2016; Charles and York, 2019). Research has shown that even poor weed infestation during this period can significantly impact cotton yields (Oerke, 2006; Dogan et al., 2015).

Problems with primary weed infestation in cotton are solved to a considerable extent (Chachalis and Galanis, 2007; Cardoso, 2011). The problem of secondary weed infestation of annual and perennial graminaceous weeds during cotton vegetation is also solved to a great extent by using antigraminaceous herbicides (Gao, 2005). A big issue in cotton cultivation is secondary weed infestation (Boz, 2000; Bükün, 2005). Data on herbicides for efficient control of secondary emerging annual and perennial broadleaf weeds

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in conventional cotton growing technology are rather scarce even on a global scale. In the application of the herbicide during the growing season of the cotton often there is a manifestation of phytotoxicity that affects the yield (Ashok et al., 2006; Jiang et al., 2012; Barakova and Delchev, 2016; Barakova et al., 2018, 2019 и 2021). Information on glyphosate-tolerant cotton cultivars is presented (Culpepper, 2006; Werth et al., 2006; Gaylon et al., 2015; Spielman et al., 2015). When glyphosate-tolerant (Roundup Ready technology) or glufosinate-tolerant (Liberty Link technology) cotton cultivars are grown, control of all weeds is obtained (graminaceous and broadleaf, annual and perennial). These technologies are widely used in major cotton-producing countries. However, these cultivars are GMOs and are banned within the territory of the European Union, incl. Bulgaria. This makes the present study particularly relevant not only for Bulgaria, but also for all cotton producing countries within the European Union.

The aim is to study the selectivity and stability of the effects of three different rates of the herbicide Envoke on cotton under different weather conditions.

Material and methods

The research was conducted during the period of 2020-2022 in the experimental field of Field Crops Institute - Chirpan. The experiment was carried out in 4 repetitions according to the block method (Shanin, 1977; Dimova and Marinkov, 1999). The size of the trial plot was 10 m^2. In a three-factor field experiment, the effect of the herbicidal product Envoke (containing 75% trifloxysulforon-sodium) applied during the vegetation was tested on two cotton cultivars. Factor A includes the three years of the study. Factor B includes the cultivars Chirpan-539 and Helius. Factor C includes the herbicide Envoke, applied in 3 doses – 10 g ha^{-1}, 15 g ha^{-1}, 20 g ha^{-1}, once and two times during the 4-5 leaf and budding stages of cotton. The tested variants are indicated in Table 1. Due to its weak adhesion, the herbicidal product Envoke was imported together with the adjuvant Supersonic. All variants during the cotton growing season were applied with a backpack sprayer with a working solution of 300 $l.ha^{-1}$.

Table 1. Investigated variants of the vegetation-applied herbicide Envoke (75% trifloxysulforon-sodium) in two cotton cultivars

№	Cultivar	Stages of treatment	Doses
1.	Chirpan-539	Zero control	
2.		Industrial control	
3.		4-5 leaf	10 g ha^{-1}
4.			15 g ha^{-1}
5.			20 g ha^{-1}
6.		budding stage	10 g ha^{-1}
7.			15 g ha^{-1}
8.			20 g ha^{-1}
9.		4-5 leaf and	10 + 10 g ha^{-1}
10.		budding stage	15 + 15 g ha^{-1}
11.			20 + 20 g ha^{-1}
12.	Helius	Zero control	
13.		Industrial control	
14.		4-5 leaf	10 g ha^{-1}
15.			15 g ha^{-1}
16.			20 g ha^{-1}
17.		budding stage	10 g ha^{-1}
18.			15 g ha^{-1}
19.			20 g ha^{-1}
20.		4-5 leaf and	10 + 10 g ha^{-1}
21.		budding stage	15 + 15 g ha^{-1}
22.			20 + 20 g ha^{-1}

Herbicide Envoke was used with adjuvant Supersonic.

The experiment was carried out against the background of the herbicide combination Dual Gold 960 EC (S-metolachlor) - 1.2 l ha^{-1} + Smerch 24 EC (oxyfluorfen) - 1.0 l ha^{-1}. It was applied after sowing before cotton emergence, for control of primary weed infestation of grass and broadleaf weeds with a working solution of 400 l ha^{-1}. The zero control was untreated. Weeds in the industrial control were removed by manual hoeing - 3 times during the vegetation.

The selectivity was established by EWRS (at score 1 the plants are healthy, and at score 9 - total destruction of plants). The observations were done on the 20th and on the 40th day after treatment. The selectivity of the herbicide was established through their influence on seed yield.

The math processing of the data was done according to the method of analyses of variance

(Shanin 1977; Barov, 1982; Lidanski 1988). The stability of herbicides and herbicide combinations for yield with relation to years was estimated using the stability variances σ_i^2 and S_i^2 of Shukla (1972), the ecovalence Wi of Wricke (1962) and the stability criterion YSi of Kang (1993).

Results and discussion

The dominant weeds in the experiment were mainly late spring annual broadleaf species - *Xanthium strumarium* L., *Amaranthus retroflexus* L., *Amaranthus albus* L., *Amaranthus blitoides* W., *Chenopodium album* L., *Solanum nigrum* L., *Polygonum aviculare* L., to a lesser extent *Hibiscum trionum* L., *Portulaca oleracea* L., *Datura stramonium* L., *Abutilon teophrasti* Medic., *Tribulus terrestris* L.

Annual grass weeds were less common, as single plants: *Panicum sanguinale* L., *Echinochloa crus-galli* L., *Setaria viridis* Beauv., *Setaria glauca* Beauv. and *Setaria verticilata* Beauv.

The perennial species reported in the experiment were the broadleaf weeds *Cirsium arvense* Scop. and Convolvulus arvensis L.

The sunflower plants (*Helianthus annuus* L.) as volunteers were present (from Clearfield and Express Sun sunflower hybrids), grown two years before as a preceding crop. In the previous year (before the sunflowers), durum wheat (*Triticum durum* Desf.) was grown before cotton.

All kinds of weeds were met in various stages of development – from second leaf to flowering stage.

Table 2. Selectivity of the herbicide Envoke on cotton plants by EWRS scale

Factor A	Factor B		Selectivity of the herbicide Envoke	
Cultivar	Herbicide	Applied treatment	20th day	40th day
Chirpan-539	Zero control		-	-
	Industrial control		-	-
	Envoke - 10 g ha^{-1}	4-5 leaf	1	1
	Envoke - 15 g ha^{-1}		1	1
	Envoke - 20 g ha^{-1}		2	1
	Envoke - 10 g ha^{-1}	budding stage	1	1
	Envoke - 15 g ha^{-1}		2	1
	Envoke - 20 g ha^{-1}		2	1
	Envoke – 10 + 10 g ha^{-1}	4-5 leaf and budding stage	2	1
	Envoke – 15 + 15 g ha^{-1}		2	1
	Envoke – 20 + 20 g ha^{-1}		2	1
Helius	Zero control		-	-
	Industrial control		-	-
	Envoke - 10 g ha^{-1}	4-5 leaf	1	1
	Envoke - 15 g ha^{-1}		1	1
	Envoke - 20 g ha^{-1}		2	1
	Envoke - 10 g ha^{-1}	budding stage	1	1
	Envoke - 15 g ha^{-1}		2	1
	Envoke - 20 g ha^{-1}		2	1
	Envoke - 10 + 10 g ha^{-1}	4-5 leaf and budding stage	2	1
	Envoke - 15 + 15 g ha^{-1}		2	1
	Envoke - 20 + 20 g ha^{-1}		2	1

In the two cotton cultivars - Chirpan-539 and Helius, on average for the three-year period, on the 20th day after treatment, phytotoxicity was observed - score 2 in the following variants: Envoke 20 g ha^{-1},

applied in stage 4-5 leaf of the cotton, Envoke 15 g ha^{-1} and Envoke 20 g ha^{-1} in the budding stage and Envoke in doses of 10 g ha^{-1}, 15 g ha^{-1} and 20 g ha^{-1} applied twice during the growing season (Table 2). Signs of phytotoxicity were expressed in light necrotic spots on the leaves. On the 40th day after treatment, no phytotoxicity was observed. In all other variants, no phytotoxic manifestations were reported, both on the 20th and on the 40th day.

Table 3. Influence of the herbicide Envoke on raw cotton yields (2020-2022)

Factor A	Factor B		2020		2021		2022	
Cultivar	Herbicide	Applied treatment	kg.ha^{-1}	%	kg.ha^{-1}	%	kg.ha^{-1}	%
Chirpan-539	Zero control		1320	100	590	100	988	100
	Industrial control		1460	110.6	718	121.7	1410	142.7
	Envoke-10 g ha^{-1}	4-5 leaf	1473	111.6	608	103.1	1520	153.9
	Envoke-15 g ha^{-1}		1415	107.2	583	98.8	1438	145.6
	Envoke-20 g ha^{-1}		1400	106.1	598	101.4	1408	142.5
	Envoke-10 g ha^{-1}	budding stage	1435	108.7	685	116.1	1270	128.6
	Envoke-15 g ha^{-1}		1519	115.1	688	116.6	1340	135.6
	Envoke-20 g ha^{-1}		1535	116.3	695	117.8	1393	141.0
	Envoke - 10 + 10 g ha^{-1}	4-5 leaf and budding stage	1368	103.6	530	89.8	1395	141.2
	Envoke - 15 + 15 g ha^{-1}		1485	112.5	520	88.1	1380	139.7
	Envoke - 20 + 20 g ha^{-1}		1378	104.4	520	88.1	1383	140.0
Helius	Zero control		1093	100	460	100	963	100
	Industrial control		1303	119.2	648	140.9	1268	131.7
	Envoke-10 g ha^{-1}	4-5 leaf	1503	137.5	508	110.4	1233	128.0
	Envoke-15 g ha^{-1}		1480	135.4	548	119.1	1205	125.1
	Envoke-20 g ha^{-1}		1470	134.5	505	109.8	1210	125.7
	Envoke-10 g ha^{-1}	budding stage	1393	127.5	555	120.7	1238	128.6
	Envoke-15 g ha^{-1}		1480	135.4	580	126.1	1205	125.1
	Envoke-20 g ha^{-1}		1368	125.2	618	134.4	1333	138.4
	Envoke - 10 + 10 g ha^{-1}	4-5 leaf and budding stage	1230	112.5	510	110.9	1313	136.4
	Envoke - 15 + 15 g ha^{-1}		1335	122.1	538	117.0	1340	139.2
	Envoke - 20 + 20 g ha^{-1}		1310	119.9	543	118.1	1373	142.6

LSD, kg.ha^{-1}:

F.A	p≤5%=39	p≤1%=52	p≤0.1%=67
F.B	p≤5%=32	p≤1%=42	p≤0.1%=66
F.C	p≤5%=75	p≤1%=100	p≤0.1%=128
AxB	p≤5%=56	p≤1%=74	p≤0.1%=94
AxC	p≤5%=131	p≤1%=172	p≤0.1%=222
BxC	p≤5%=107	p≤1%=141	p≤0.1%=181
AxBxC	p≤5%=185	p≤1%=244	p≤0.1%=313

The period 2020-2022 included years with varying temperatures and rainfalls. The year 2020 was the most favorable for cotton.

When treated in the 4-5 leaf stage, the highest cotton yields were obtained with the use of the herbicide Envoke at a rate of 10 g ha^{-1} in both cultivars (Table 3). The higher doses of 15 g ha^{-1} and 20 g ha^{-1} during this stage resulted in a lower yield increase. This trend was present in all three years of the study. Apparently, increasing the herbicide dose during this early stage did not have a favorable effect on the development of young cotton plants.

When treated in the budding stage, the highest yields of cotton in all three years were obtained with the use of the Envoke herbicide at a dose of 20 g ha^{-1} in both cultivars. The differences with the yields at the lower doses of 10 g ha^{-1} and 15 g ha^{-1} are small and are mathematically unproven.

During the years of the study, the highest yields in both cultivars of cotton were obtained with the two-fold applications of the herbicide Envoke during the 4-5 leaf and budding stages. The differences between the three doses in the double treatment are mathematically unproven.

Table 4. Analysis of variance for cotton yield

Source of variation	Degrees of freedom	Sum of squares	Influence of factor, %	Mean square	Fisher's criteria	Probability level
Total	263	412148.0	100	-	-	-
Tract of land	3	485.0	0.1	161.7	0.9	ns
Variants	65	377377.8	91.6	5805.8	33.0	***
Factor A - Years	2	346368	84.0	173184.0	984.9	***
Factor B - Cultivars	1	3995.3	1.0	3995.3	22.7	***
Factor C-Herbicides	10	15324.8	3.7	1532.5	8.7	***
AxB	2	236.5	0.1	118.3	0.7	ns
AxC	20	7749.8	1.9	357.5	2.2	**
BxC	10	563.3	0.1	56.3	0.3	ns
AxBxC	20	3140.3	0.8	157.0	0.9	ns
Pooled error	195	34285.3	8.3	175.8	-	-

*p≤5% **p≤1% ***p≤0.1%

In the analysis of variance in relation to the yield of raw cotton (Table 4), it is established that the influence of the tested variants is 91.5% of the total variation of the data, proven with differences p≤0.1%. The years have the strongest influence on the yield – 84.0% of that of the variants. It is determined by the unequal reaction of the variants to the change in the environmental conditions. This is due to the large differences in weather conditions during the three years of the study. The herbicide has a stronger impact on cotton yield – 3.7%, compared to cultivars. The influence of herbicides is very well proven at p≤0.1%. The strength of influence of cultivars is 1.0%. Their influence is also very well proven at p≤0.1%. There is no proven interaction of the cultivars with the conditions of the years (A x B). There is an interaction of herbicides with the conditions of the years (A x C) – 1.9%. It is well proven for differences p≤1%. There is no proven interaction of the herbicides with the cultivars (B x C). This means that the two cotton cultivars Chirpan-539 and Helius respond equally to the Envoke herbicide, regardless of its rates and application time. The interaction between the three

experimental factors (A x B x C) is also unproven.

Based on the proven interaction herbicide x year, stability parameters for each variant for raw cotton yield with relation to years were evaluated (Table 5). Stability variances σ_i^2 and S_i^2 of Shukla, the ecovalence Wi of Wricke and the stability criterion YS_i of Kang were calculated.

Table 5. Stability parameters for the herbicide Envoke for raw cotton yield with relation to years

Factor A	Factor B		Stability parameters				
Cultivar	Herbicide	Applied treatment	$\bar{x}$	$\sigma_i 2$	$S_i 2$	W_i	YS_i
Chirpan-539	Zero control		899	1346.5**	140.2	2472.2	-9
	Industrial control		1196	30.6	1.7	79.7	22+
	Envoke-10 g ha^{-1}	4-5 leaf	1200	387.3	415.2	728.4	23+
	Envoke-15 g ha^{-1}		1145	193.5	257.9	375.9	19+
	Envoke-20 g ha^{-1}		1135	96.4	173.9	199.4	18+
	Envoke-10 g ha^{-1}	budding stage	1130	206.0	185.9	398.7	17+
	Envoke-15 g ha^{-1}		1179	87.4	176.6	183.1	21+
	Envoke-20 g ha^{-1}		1208	29.2	70.9	77.2	24+
	Envoke - 10 + 10 g ha^{-1}	4-5 leaf and budding stage	1098	222.0	281.9	427.8	13+
	Envoke - 15 + 15 g ha^{-1}		1128	312.1	-9.8	591.5	16+
	Envoke - 20 + 20 g ha^{-1}		1093	201.1	196.9	389.8	12+
Helius	Zero control		835	603.6*	69.7	1121.5	-6
	Industrial control		1073	247.9	10.0	474.9	6
	Envoke-10 g ha^{-1}	4-5 leaf	1081	515.8	695.8*	961.9	9
	Envoke-15 g ha^{-1}		1078	417.6	792.0*	783.4	8
	Envoke-20 g ha^{-1}		1038	137.6	235.0	274.4	3
	Envoke-10 g ha^{-1}	budding stage	1062	48.9	11.5	113.0	4
	Envoke-15 g ha^{-1}		1120	126.2	186.4	253.6	15+
	Envoke-20 g ha^{-1}		1106	24.6	35.9	68.9	14+
	Envoke - 10 + 10 g ha^{-1}	4-5 leaf and budding stage	1018	279.2	565.2	531.7	2
	Envoke - 15 + 15 g ha^{-1}		1071	83.5	159.4	175.9	5
	Envoke - 20 + 20 g ha^{-1}		1075	228.0	456.4	438.6	7
	Mean		1089				11.1
	LSD (p=0.05)		8.9				

Stability variances (σ_i^2 и S_i^2) of Shukla, which recorded linear and non-linear interactions, respectively, unidirectional evaluated the stability of the variants. These variants which showed lower values were considered to be more stable because they interacted less with the environmental conditions. Negative values of the indicators σ_i^2 and S_i^2 are considered 0. At high values of either of the two parameters - σ_i^2 and S_i^2, the variant is considered unstable. At the ecovalence W_i of

Wricke, the higher the values of the index, the more unstable the variant.

On this basis, using the first three parameters of stability, it is found that the most unstable are the untreated controls in the two cotton cultivars and the Envoke herbicide in doses of 10 g ha^{-1} and 15 g ha^{-1} in the cultivar Helius. In them, the values of the stability variances σ_i^2 and S_i^2 of Shukla and of the equivalency W_i of Wricke are the highest and mathematically proven. The volatility is mainly due to the significant differences in the raw cotton yields of these variants in the individual years of the trial, as weather conditions affect them the most. In the untreated controls, there is instability of the linear type - proven values of σ_i^2 and S_i^2 values are unproven. In the variants with the herbicide Envoke in doses of 10 g ha^{-1} and 15 g ha^{-1} in the cultivar Helius there is instability of the linear type - proven values of S_i^2. The values of σ_i^2 are unproven. The remaining variants exhibited high stability in terms of raw cotton yield, regardless of changes in weather conditions during the cotton growing season.

In order to make a comprehensive assessment of the effectiveness of each variant, both its effect on cotton yield and its stability - the response of the crop to it in different years must be taken into account. Valuable information about the technological value of the variant gives the stability criterion YS_i of Kang for simultaneous assessment of yield and stability, based on the reliability of differences in yield and variance of interaction with the environment. The value of this criterion is that by using non-parametric methods and statistical evidence of differences, we obtain a summary assessment, ranking the options in descending order according to their economic value.

Generalized stability criterion YS_i of Kang, taking into account both the stability and value of yields, gives negative assessments of untreated controls, characterizing them as the most unstable and the lowest yielding. According to this criterion, all variants with the herbicide Envoke in the cultivar Chirpan-539 and the variants with herbicide Envoke in doses of 15 g ha^{-1} and 20 g ha^{-1} in cultivar Helius appear to be technologically the most valuable. These options combine high yield values and high stability of this indicator in different years. From the point of view of cotton growing technology, the remaining herbicide-treated variants of cultivar Helius receive high marks. They combine good yields with good stability during the individual years of the study. The untreated controls in both cultivars of cotton are the only ones that receive negative evaluations. This is due to the high number of weeds and sunflower volunteers.

Conclusion

It was found that after the application of the herbicidal product Envoke in three rates during the vegetation and in two growth stages (4-5 leaf and budding stages of cotton), no phytotoxic effect on the crop was observed and it is selective to the two cultivars grown in the study (Chirpan-539 and Helius).

The highest yields in both cotton cultivars were obtained with the two-fold application of the herbicide Envoke during the 4-5 leaf and budding stages. Technologically, the most valuable were all variants with the herbicide Envoke for the cultivar Chirpan-539 and the variants with the herbicide Envoke in doses of 15 g ha^{-1} and 20 g ha^{-1} for the cultivar Helius. These options combine high yield values and high stability of this indicator in different years. The untreated controls in the two cotton cultivars are the only ones that receive negative evaluations. This is due to the high number of weeds and sunflower volunteers.

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