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INFLUENCE OF THE VEGETATION-APPLIED HERBICIDES "ENVOKE" AND "STAPLE" ON SOME STRUCTURAL ELEMENTS OF PRODUCTIVITY AND YIELD OF COTTON (*Gossypium hirsutum* L.)

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Abstract

The research was conducted during the period 2021-2023 on the testing grounds of the Field Crops Institute in Chirpan with cotton cultivar Helius (Gossypium hirsutum L.). In a two-factor field experiment, the effect of two vegetation-applied herbicides: "Staple", containing 33.6% pyrithiobac-sodium, and "Envoke", containing 75% trifloxysulforon-sodium. Factor A included the herbicides "Staple" and "Envoke", applied once and twice during the phenophases of 4-5 leaf and bud development of cotton. Factor B included the three years of study. The highest yields of cotton were obtained with the herbicide combination "Staple" + "Envoke", applied once and twice during the phenological stages of 4-5 leaf and budding of cotton. The vegetation herbicides "Staple" and "Envoke", when applied once and twice during the phenophases of 4-5 leaf and bud development of cotton, did not affect the percentage of boll opening and the boll weight of the cotton cultivar Helius.

Key words*: cotton, vegetation-applied herbicides, boll opening, boll weight, seed cotton yield.*

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INTRODUCTION

Weed infestation is an important factor that significantly affects the quantity and quality of agricultural crops. As a result of weed infestation, the reduction of harvest yields averages between 10% and 50% in different crops (Delchev, 2019; 2019a; 2021; 2022). This requires regular and effective weed control measures.

Weed infestation with annual and perennial broadleaf weeds during the vegetation period is the main problem in conventional cotton growing technology (Culpepper, 2006; Werth et al., 2006; Berger et al., 2015; Jabran, 2016; Charles & York, 2019). Depending on the type of weeds and their quantity, the yield reduction can vary from 10 to 90% of this crop (Oerke, 2006; Dogan et al., 2015). Manual cultivation, through hoeing several times, was carried out in the cotton fields to control those weeds in the past. In contemporary agriculture, that proves unprofitable, and weed control is mainly carried out using herbicides.

The problems have been largely resolved with primary weed infestation in cotton (Chachalis & Galanis, 2007; Cardoso, 2011). The use of herbicides against weeds of the *Graminaceae* family has also largely solved the problem of secondary weed infestation with annual and perennial weeds of that family during the vegetation period of that crop (Gao, 2005). However, secondary weed infestation is a problem in contemporary cotton cultivation. (Boz, 2000; Bükün, 2005; Barakova, 2017). Globally, data is scarce on herbicides for effective control of secondarily developing broadleaf weeds in the conventional cotton growing technology. Herbicides, when applied during the period of vegetation of the crop, often manifest symptoms of phytotoxicity that affects yield structural elements, such as boll opening percentage and boll weight, and yield (Ashok et al., 2006; Jiang et al., 2012; Barakova & Delchev, 2016; Barakova et al., 2018; 2019; 2021). The search is continuing for effective and selective cotton herbicides. There is also a worldwide shortage of studies on their influence on the structural elements of cotton productivity and yield.

The purpose of the present study is to investigate the influence of the vegetation-applied herbicides "Staple" and "Envoke" on some structural elements of productivity, such as percentage of boll opening and boll weight, and yield in one cotton cultivar under different agrometeorological conditions.

MATERIALS AND METHODS

The research was conducted in the period 2021-2023 on the testing grounds of the Field Crops Institute in Chirpan. The experiment was carried out in 4 repetitions according to the block method (Shanin, 1977; Dimova &Marinkov, 1999). The experiments were conducted on a plot of land with a size of 10 square meters.

In a two-factor field experiment with cotton of 'Helius' cultivar, the influence of two vegetation herbicides was tested: "Staple" containing 33.6% pyrithiobac-sodium and "Envoke" containing 75% trifloxysulfuron-sodium. Factor A includes the herbicides "Staple" and "Envoke", which were applied once during the phenological stage of 4-5 leaf and twice during the phenological stages of 4-5 leaf and budding of cotton. Factor B includes the three years of the study. The tested variants are indicated in Table 1. Due to its weak adhesion, "Staple" was applied together with the adjuvant "Trend", and "Envoke" was applied together with the adjuvant "Supersonic". All variants during the cotton growing season were applied with a backpack sprayer with a working solution of 300 liters per hectare (10,000 square meters).

Table 1. Investigated variants of the vegetation-applied herbicides Staple (33.6% pyrithiobac-sodium) and Envoke (75% trifloxysulforon-sodium) in the cotton cultivar

№	Herbicides	Active substances	Doses	Phenological stages during treatment
1	Untreated control			
2	Economic control			
3	Staple	33.6% pyrithiobac-sodium	100 ml/ha	4-5 leaf
4	Envoke	75% trifloxysulforon-sodium	20 g/ha	
5	Staple+Envoke	33.6 % pyrithiobac-sodium + 75 % trifloxysulforon-sodium	100 ml/ha + 20 g/ha	
6	Staple	33.6% pyrithiobac-sodium	100 + 100 ml/ha	4-5 leaf and budding
7	Envoke	75% trifloxysulforon-sodium	20 + 20 g/ha	
8	Staple+Envoke	33.6 % pyrithiobac-sodium + 75 % trifloxysulforon-sodium	100 + 100 ml/ha + 20 + 20 g/ha	
The herbicide Staple was used with the adjuvant "Trend" - 500 ml/ha. The herbicide Envoke was used with the adjuvant "Supersonic" - 500 ml/ha.				

The experiment was carried out against the background of the herbicide combination "Dual Gold 960 EC" (S-metolachlor) at 1.2 liters per hectare + "Smerch 24 EC" (oxyfluorfen) at 1.0 liter per hectare. It was applied after the sowing before the germination of the cotton, with a working solution of 400 liters per hectare, to control the initial weed proliferation of weeds of the *Graminaceae* family as well as the proliferation of broadleaf weeds.

The untreated control was neither treated nor cultivated. The weeds in the economic control were removed through manual cultivation (hoeing three times) during the vegetation period of the cotton.

The dominant weeds that determined the infestation with 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 *Hibiscus trionum* L., *Portulaca oleracea* L., *Datura stramonium* L., *Abutilon theophrasti* Medic., *Tribulus terrestris* L.

The annual weeds of the *Graminaceae* family 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 volunteer plants of sunflower (*Helianthus annuus* L.) were from "Clearfield" and

"Express Sun" sunflower hybrids, grown two years ago as a predecessor. In the previous year, durum wheat (*Triticum durum* Desf.) had been grown before cotton.

All types of weeds were encountered in different phenological stages of development: from the second leaf stage to the flowering stage.

Cotton vegetation during the three years of the study occurred under unfavorable moisture and temperature conditions (Table 2). In 2021, insufficient soil moisture and high temperatures in the first half of May made the seed germination very difficult. Precipitation in June, July, and August was slightly below normal, with the drought continuing in August when precipitation was 44.5 mm less than the norm. Temperature sums in July and August, respectively, were 53°C and 50°C higher than the ones for several years. The precipitation in April and May 2022 was 36 mm and 29.4 mm, which is respectively 6.6 mm and 29.7 mm lower than the average for several years. The temperature sum in May was 9°C higher than the average values for several years. In 2022, the precipitation in July is 45.7 mm below the norm, and the temperature sums in July and August are 34°C and 43°C above the norm. Temperature sums for April and May 2023 were 38°C and 53°C lower than the average for several years, which delayed cotton germination. During July and August, the total amount of precipitation is 39.2 mm lower than the average for several years, and the temperature sum for the same period (July and August) is 150°C above the temperature sum for several years. During the three years of the study, the temperatures in July and August - the period of flowering and boll formation - were significantly higher than the average for several years, and, combined with the lack of rainfall, had a very unfavorable effect on the growth and the development of cotton.

Table 2. Meteorological characteristics for the IPK region - Chirpan during the cotton growing season compared to the values for several years, 2021-2023

Years	Months						Σ_{IV-IX}	$\Sigma_{VI-VIII}$	Σ_{V-IX}
	IV	V	VI	VII	VIII	IX			
Sum of temperatures Σ t ^{0}C									
1989-2017	371	528	638	740	739	559	3575	2117	3204
2021	309	524	616	793	789	564	3595	2198	3286
±	-62	-4	-22	+53	+50	+5	+20	+81	+82
2022	367	537	659	774	782	565	3684	2215	3317
±	-4	+9	+21	+34	+43	+6	+109	+98	+113
2023	333	475	628	818	811	617	3682	2257	3349
±	-38	-53	-10	+78	+72	+58	+107	+140	+145
Rainfall - mm									
1989-2017	42.6	59.1	48.4	53.4	37.7	53.4	294.6	139.5	252.0
2021	84.0	34.9	42.8	49.0	34.4	5.0	250.1	126.2	166.1
±	+41.4	-24.2	-5.6	-4.4	-3.3	-48.4	-44.5	-13.3	-55.9
2022	36	29.4	80.5	7.7	68.8	34.9	257.3	157	221.3
±	-6.6	-29.7	+32.1	-45.7	+31.1	-18.5	-37.3	+17.5	-30.7
2023	68.2	54.8	69.5	25.4	26.5	30.1	274.5	121.4	206.3
±	+25.6	-4.3	+21.1	-28	-11.2	-23.3	-20.1	-18.1	-45.7

The yield and some of its structural elements were studied: the percentage of boll opening and the weight of the boll. Seed cotton yield is determined for all variants in kg/ha. The percentage of boll opening was reported as a percentage (%) and was determined based on

the number of open bolls per 40 plants per variant (with 10 plants from each repetition). The boll weight was determined based on the total number of bolls from the analyzed 40 plants per variant and was reported in grams (g). Data was processed by analysis of variance (Shanin, 1977; Barov, 1982; Lidanski, 1988).

RESULTS AND DISCUSSIONS

On average for the period of the research, with a single application during the phenological stage of 4-5 leaf, the highest cotton yields of 1,253 kg/ha were obtained with the use of the tank herbicide mixture "Staple' + "Envoke" (Table 3). The independent use of the herbicide "Staple" during this phenological stage leads to a slightly stronger increase in yield reaching 1,164 kg/ha when compared to the independent use of the herbicide "Envoke" with the yield reaching 1,118 kg/ha.

When treated twice during the phenological stages of 4-5 leaf and budding, the independent use of "Staple" leads to higher yields of 1,203 kg/ha, compared to the application of "Envoke" with 1,084 kg/ha. When treated twice with the tank herbicide mixture "Staple" + "Envoke", the highest yield was achieved with 1,215 kg/ha.

The yield obtained from the economic control was 1,278 kg/ha, and that of the untreated control was 931 kg/ha.

The higher yield of the "Staple" + "Envoke" herbicide tank mix is due to the both herbicides demonstrate synergism when used as a tank mixture to broaden the spectrum of broadleaf weeds controlled.

Table 3. Influence of the vegetation-applied herbicides "Staple" (33.6% pyrithiobac-sodium) and "Envoke" (trifloxysulforon-sodium) on the seed cotton yield (2021-2023)

Factor A		Factor B			
Stages of treatment	Herbicides	2021	2022	2023	Mean
		kg/ha	kg/ha	kg/ha	kg/ha
Untreated control		510	963	1,320	931
Economic control		698	1,318	1,818	1,278
4-5 leaf	Staple	713	1,180	1,600	1,164
	Envoke	480	1,210	1,663	1,118
	Staple + Envoke	883	957	1,920	1,253
4-5 leaf and budding stage	Staple	658	1,300	1,653	1,203
	Envoke	543	1,173	1,538	1,084
	Staple+Envoke	843	1,220	1,583	1,215

LSD, kg/ha:

F.A	p≤5%=164	p≤1%=217	p≤0.1%=282
F.B	p≤5%=100	p≤1%=133	p≤0.1%=173
A x B	p≤5%=238	p≤1%=376	p≤0.1%=488

From the analysis of the variance of seed cotton yield (Table 4), it was found that the influence of the tested variants was 85.7% of the total variation, proven at p≤0.1%. The years have the strongest influence on the yield with 75.4% of that of the variants. The reason for this is the great differences in agrometeorological conditions during the three years of the study. The influence of years is very well proven at p≤0.1%. Herbicides also affect cotton yield by 5.2%. Their influence is proven at p≤1%. There is no proven interaction of herbicides with the weather conditions of the years (A x B). This means that "Staple" and "Envoke" directly affect raw cotton yield during the years of the study.

Table 4. Analysis of variance for the seed cotton yield

Source of variation	Degrees of freedom	Sum of squares	Influence of factor, %	Mean square	Fisher's criteria	Probability level
Total	95	200,123.5	100	-	-	-
Tract of land	3	839.5	0.4	279.8	0.7	ns
Variants	123	171,460.3	85.7	7,454.8	18.5	***
Factor A - Herbicides	7	10,484.0	5.2	1,497.7	3.7	**
Factor B - Years	2	150,876.4	75.4	75,439.2	187.1	***
A x B	14	10,099.9	5.0	721.4	1.8	ns
Pooled error	69	27,823.8	13.9	403.2	-	-

*p≤5% **p≤1% ***p≤0.1%

The percentage of boll opening is closely related to the early ripening of the cultivar, the September harvest (cotton harvested by 30 September), and the economic yield. The higher the percentage of boll opening, the earlier the harvest of the cultivar.

On average, the percentage of boll opening varied from 72.0% to 83.6% (Table 5). With the independent use of “Staple” or “Envoke” and with their tank mixture, the values of this indicator are higher than that of the economic control. The increase against the backdrop of economic control has been proven mathematically. This is a positive effect of the use of “Staple” and “Envoke”, as the herbicides have a positive effect on the rate of boll opening in cotton.

Table 5. Influence of the vegetation-applied herbicide “Envoke” (trifloxysulforon-sodium) on the percentage of open bolls (2021-2023)

Factor A		Factor B			
Stages of treatment	Herbicides	2021	2022	2023	Mean
		%	%	%	%
Untreated control		35.6	88.2	92.2	72.0
Economic control		44.0	84.3	88.9	72.4
4-5 leaf	Staple	60.4	98.8	91.5	83.6
	Envoke	49.3	82.9	91.1	74.4
	Staple+Envoke	54.5	94.9	86.2	78.5
4-5 leaf and budding stage	Staple	38.3	94.3	95.0	75.9
	Envoke	40.8	92.3	94.5	75.9
	Staple+Envoke	47.9	89.1	96.8	78.0

LSD, %:
F.A p≤5%=8.8 p≤1%=11.7 p≤0.1%=15.2
F.B p≤5%=5.4 p≤1%=7.2 p≤0.1%=9.3
A x B p≤5%=15.3 p≤1%=20.3 p≤0.1%=26.3

Through the analysis of variance concerning the percentage of boll opening (Table 6), it was found that the influence of the tested variants was 86.4% of the total variation of the data, very well proven at p≤0.1%.

Years had a stronger effect on the rate of boll opening compared to the effect of the herbicides - 79.6% of that of the variants.

This is due to the large differences in agrometeorological conditions during the cotton growing season for the three years of the study.

The influence of years is very well proven at p≤0.1%.

The herbicides affect the rate of opening in cotton with 3.2%. Their influence is proven at p≤5%.

There is no proven interaction of the herbicides with the meteorological conditions of the years (A x B).

Table 6. Analysis of the variance for the percentage of open bolls

Source of variation	Degrees of freedom	Sum of squares	Influence of factor, %	Mean square	Fisher's criteria	Probability level
Total	95	60,337.9	100	-	-	-
Tract of land	3	144.4	0.2	48.1	0.4	ns
Variants	123	52,124.3	86.4	2,266.3	19.4	***
Factor A - Herbicides	7	1,950.5	3.2	278.6	2.4	*
Factor B - Years	2	48,055.63	79.6	24,027.8	205.5	***
A x B	14	2,118.1	3.5	151.3	1.3	ns
Pooled error	69	8,069.3	13.4	116.9	-	-

*p≤5% **p≤1% ***p≤0.1%

The weight of the boll is an important structural element of productivity and has a direct influence on the yield. The average weight of the boll for the period varies from 4.2 g to 4.7 g (Table 7). The herbicides "Staple" and "Envoke" and the tank herbicide mixture "Staple" + "Envoke" have been shown to increase boll weight against the backdrop of the untreated sample. This is due to their high efficacy against annual and perennial broadleaf weeds and their good selectivity against cotton. The herbicides "Staple" and "Envoke" and their herbicide combination have not been shown to affect boll weight at any of the doses applied and during any of the treatment phases.

Table 7. Influence of the vegetation-applied herbicide "Envoke" (trifloxysulforon-sodium) on the boll weight (2021-2023)

Factor A		Factor B			
Stages of treatment	Herbicides	2021	2022	2023	Mean
		g	g	g	g
Untreated control		4.4	3.8	4.6	4.2
Economic control		4.8	4.3	4.8	4.6
4-5 leaf	Staple	4.7	4.4	4.6	4.6
	Envoke	4.6	4.5	4.7	4.6
	Staple+Envoke	4.6	4.4	4.7	4.6
4-5 leaf and budding stage	Staple	4.7	4.5	4.7	4.6
	Envoke	5.3	4.3	4.5	4.7
	Staple+Envoke	4.9	4.5	4.6	4.7

LSD, g:
F.A p≤5%=0.4 p≤1%=0.5 p≤0.1%=0.7
F.B p≤5%=0.2 p≤1%=0.3 p≤0.1%=0.4
A x B p≤5%=0.7 p≤1%=0.9 p≤0.1%=1.2

Through the analysis of variance concerning the weight of the boll (Table 8), it was found that the influence of the tested variants was 29.5% of the total variation of the data, which was not proven. The years have a stronger influence on the weight of the ball compared to the effect of the herbicides with 11.6% of that of the variants and that demonstrates the great importance of the external factors in determining the magnitude of this feature. The influence of the years is well proven at p≤1%. The influence of the herbicides is 8.6%. Their influence has not been proven. There is no proven interaction of herbicides with the conditions of the years (A x B).

Table 8. Analysis of variance for the boll weight

Source of variation	Degrees of freedom	Sum of squares	Influence of factor, %	Mean square	Fisher's criteria	Probability level
Total	95	26.1	100	-	-	-
Tract of land	3	1.2	4.8	0.4	1.7	ns
Variants	123	7.7	29.5	0.3	1.3	ns
Factor A - Herbicides	7	2.2	8.6	0.3	1.3	ns
Factor B - Years	2	3.0	11.6	1.5	6.1	**
A x B	14	2.4	9.3	0.2	0.7	ns
Pooled error	69	17.2	65.7	0.2	-	-

*p≤5% **p≤1% ***p≤0.1%

CONCLUSIONS

The highest yields of cotton were obtained with the use of the herbicide combination "Staple" + "Envoke", applied once and twice during the phenological stages of 4-5 leaf and budding of cotton.

The independent use of the herbicide "Staple" leads to higher yields, compared to the independent application of the herbicide "Envoke".

It was found that the independent use of the vegetation herbicides "Staple" and "Envoke" and their herbicide combination, applied once and twice during the phenological stages of 4-5 leaf and budding of cotton, did not affect the percentage of boll opening and boll weight in the "Helius" cultivar.

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