Bulgarian Journal of Agricultural Science, 25 (Suppl. 3) 2019
Agricultural Academy

Stability and selectivity of some herbicides, herbicide combinations and herbicide tank mixtures on winter forage pea (*Pisum sativum* L. var. *arvense*)

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Abstract

Delchev, G. & Delchev, D. (2019). Stability and selectivity of some herbicides, herbicide combinations and herbicide tank mixtures on winter forage pea (*Pisum sativum* L. var. *arvense*). *Bulg. J. Agric. Sci., 25* (Suppl. 3), 53–58

The research was conducted during 2015 – 2017 on pellic vertisol soil type. Under investigation was Bulgarian winter forage pea cultivar Mir (*Pisum sativum var. arvense*). Factor A included the years of investigation. Factor B included untreated control and 2 soil-applied herbicides – Dual gold 960 EC (S-metolachlor) – 1.5 $l.ha^{-1}$, Stomp aqua (pendimethalin) – 3 $l.ha^{-1}$. Factor C included untreated control, 5 foliar-applied herbicides – Basagran 480 CL (bentazone) – 2 $l.ha^{-1}$, Pulsar 40 (imazamox) – 1.2 $l.ha^{-1}$, Korum (bentazone + imazamox) – 1.25 $l.ha^{-1}$, Zencor 70 WG (metribuzine) – 500 $g.ha^{-1}$, Maton 600 EK (2.4-D ethylhexyl ester) – 100 $ml.ha^{-1}$ and 2 herbicide tank mixtures – Zencor 70 WG (metribuzine) – 500 $g.ha^{-1}$ + Targa super 5 EC (quizalofop-P-ethyl) – 2 $l.ha^{-1}$, Maton 600 EK (2.4-D ethylhexyl ester) – 100 $ml.ha^{-1}$ + Targa super 5 EC (quizalofop-P-ethyl) – 2 $l.ha^{-1}$. Soil-herbicides were applied during the period after sowing before emergence. Foliar herbicides were applied during 2 – 3 real leaf stage of the pea. The highest yields of winter forage pea seeds are obtained by treatment with foliar-applied herbicide Korum after soil-applied herbicides Stomp aqua and Dual gold. High yields are obtained also by treatment with foliar-applied herbicide Pulsar after soil-applied herbicides Stomp aqua and Dual gold, as well as by foliar treatment with herbicide tank-mixture Zencor + Targa super after soil-applied herbicides Stomp aqua and Dual gold. Herbicide Maton and herbicide tank mixture Maton + Targa super, both in separated use and in combined use with soil-applied herbicides Dual gold and Stomp aqua are the most unstable for seed yield. Combinations of foliar-applied herbicide Korum with soil-applied herbicides Stomp aqua and Dual gold are technological the most valuable. They are followed by combinations of foliar-applied herbicide Pulsar with soil-applied herbicides Stomp aqua and Dual gold. They combine high seed yield with high stability with relation to different years. Alone uses of soil-applied herbicides Dual gold and Stomp aqua, of foliar-applied herbicides Basagran, Pulsar, Korum and Zencor, and of herbicide tank mixture Zencor + Targa super have low estimates and do not be used. For complete control of all weeds and self-sown plants in winter forage pea crops, two herbicides should be combined – both soil-applied and foliar-applied.

Keywords: winter forage; pea; herbicides; herbicide combinations; seed yield; selectivity; stability

Introduction

Pea is one of the oldest crops grown for human food, for animal feed and for green meals, and in some areas for green fertilization. Its agrotechnical significance is determined by the fact that the pea improves the structure, phytosanitary conditions and microbiological processes in the soil, stabilizing its fertility (Roslon, 1990; Dimitrova, 2000; Blažinkov et al., 2015; Delchev, 2018).

Pea is particularly sensitive to herbicides, and when grown, it is important to take into account their selectivity on pea plants and not just their biological efficacy. For the control of annual broadleaved weeds after sowing before emergence period, prometrine can be used. Against annual graminaceous and some broadleaved weeds, as soil application, pre-emergence of crops and weeds, S-metolachlor is recommended. In the pre-sowing period of forage pea by incorporation, trifluraline may also be used. Due to the early sowing time of spring peas, this event is often technically unfeasible, as the soil moisture during this period is high (Dimitrova, 1998). Against annual and perennial graminaceous weeds, some foliar-applied herbicides such as propaquizafop, fluazifop, fenoxaprop and others may be used during the vegetation (3-5th leaf of weeds and 10-20 cm height of *Sorghum helepense* Pers. (Dimitrova, 2008). It has been found that foliar-applied herbicides cycloxydim and tepraloxide have a high selectivity for forage pea (Dimitrova, 2002). In a mixed type of weed infestation, it is recommended that these two herbicides must be applied in a system with foliar-applied herbicide bentazone or with soil-applied herbicide s-metolachlor, resulting in a significant increase in seed yield (Dimitrova, 2005). In the presence of broadleaved weeds in early stages of pea development, as foliar-applied (3-4th real pea leaf) are selective herbicides bentazone, metribuzin and 2M-4X.

The purpose of the investigation was to establish the selectivity and stability of some herbicides, herbicide combinations and herbicide tank mixtures on the winter forage pea by influence of different meteorological conditions.

Materials and Methods

The research was conducted during 2015-2017 on pellic vertisol soil type. Under investigation was Bulgarian winter forage pea cultivar Mir (*Pisum sativum var. arvense*). Three factors experiment was conducted under the block method, in 4 repetitions; the size of the crop plot was 15 m^2. Factor A included the years of investigation. Factor B included untreated control and 2 soil-applied herbicides – Dual gold 960 EC and Stomp aqua. Factor C included untreated control, 5 foliar-applied herbicides – Basagran 480 CL, Pulsar 40, Korum, Zencor 70 WG, Maton 600 EK and 2 herbicide tank mixtures – Zencor 70 WG + Targa super 5 EC, Maton 600 EK + Targa super 5 EC. Active substances of herbicides and their doses are shown in Table 1.

Soil herbicides were applied during the period after sowing before emergence. Foliar herbicides were applied during 2-3 real leaf stage of the pea. All of herbicides, herbicide combinations and herbicide tank-mixtures were applied in a working solution of 200 $l.ha^{-1}$. Mixing of foliar-applied herbicides was done in the tank on the sprayer. Due to of low adhesion of the herbicides Pulsar 40 and Korum were used in addition with adjuvant Dash HC – 1 $l.ha^{-1}$.

The selectivity of herbicides has been 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, herbicide combinations and herbicide tank mixtures for seed yield with relation to years was estimated using the stability variances σ_i^2 and S_i^2 of Shukla (1972), the ecovalence W_i of Wricke (1962) and the stability criterion YS_i of Kang (1993).

Results and Discussion

Data for the influence of investigated herbicides, herbicide combinations and herbicide tank mixtures on seed yield of winter forage pea (Table 2) show that the lower yield is

Table 1. Investigated variants

№	Variants	Active substance	Doses
After sowing, before emergence			
1	Control	–	–
2	Dual gold 960 EC	S-metolachlor	1.5 $l.ha^{-1}$
3	Stomp aqua	pendimethalin	5 $l.ha^{-1}$
2 – 3 real leaf stage			
1	Control	–	–
2	Basagran 480 CL	bentazone	2 $l.ha^{-1}$
3	Pulsar 40	imazamox	1.2 $l.ha^{-1}$
4	Korum	bentazone + imazamox	1.25 $l.ha^{-1}$
5	Zencor 70 WG	metribuzine	500 $g.ha^{-1}$
6	Zencor 70 WG + Targa super 5 EC	metribuzine +quizalofop-P-ethyl	500 $g.ha^{-1}$ + 2 $l.ha^{-1}$
7	Maton 600 EK	2.4-D ethylhexyl ester	1 $l.ha^{-1}$
8	Maton 600 EK + Targa super 5 EC	2.4-D ethylhexyl ester + quizalofop-P-ethyl	1 $l.ha^{-1}$ + 2 $l.ha^{-1}$

Herbicides Pulsar 40 and Korum were used in addition with adjuvant Dash HC – 1 $l.ha^{-1}$.

obtained by alone use of herbicide tank mixture Maton + Targa super – 97.2% compared to untreated control. Low yields are also obtained by alone use of herbicide Maton and by combined use of herbicide tank mixture Maton + Targa super with soil-applied herbicides Dual gold and Stomp aqua. Their use does not increase seed yield compared to untreated control, despite their very good herbicidal effect against both graminaceous and broadleaved weeds. The reason for this is their higher phytotoxicity against pea.

Alone use of soil-applied herbicides Dual gold and Stomp aqua does not proven increase seed yield compared to untreated control, because these herbicides cannot control the perennial weeds and a part of annual weeds.

Alone use of foliar-applied herbicides Pulsar and Korum increases seed yields because the all of weeds and self-sown plants are destroyed by these herbicides. Seed yields of Korum are higher than those of Pulsar. The reason for this is the longer effect of Korum and its longer control over the secondary-emerged weeds. The differences in yields between the herbicides Korum and Pulsar are mathematically unproven, because after the herbicide treatment, the pea develops rapidly, covers the whole soil surface, competes with weeds and almost prevents secondary weed infestation.

Herbicide Basargan increases yield less because of its inefficacy against graminaceous weeds and part of annual broadleaved weeds. Herbicide Zencor increases yield less because of its inefficacy against perennial broadleaved weeds and its higher phytotoxicity to pea plants.

Table 2. Influence of some herbicides, herbicide combinations and herbicide tank mixtures on seed yield of pea (2015 – 2017)

Herbicides		2015		2016		2017	
Soil-applied	Foliar-applied	kg.ha^{-1}	%	kg.ha^{-1}	%	kg.ha^{-1}	%
–	–	2314	100	2890	100	2580	100
	Basagran	2586	111.8	3299	114.2	2842	110.2
	Pulsar	2762	119.4	3390	117.3	2944	114.1
	Korum	2841	122.8	3480	120.4	3003	116.4
	Zencor	2511	108.5	3244	112.2	2755	106.8
	Zencor +Targa super	2684	116.0	3355	116.1	2924	113.3
	Maton	2377	102.7	2777	96.1	2691	104.3
	Maton +Targa super	2280	98.5	2688	93.0	2597	100.7
Dual gold	–	2378	102.8	2992	103.5	2666	103.3
	Basagran	2654	114.7	3413	118.1	2967	115.0
	Pulsar	2841	122.8	3503	121.2	3068	118.9
	Korum	2906	125.6	3589	124.2	3099	120.1
	Zencor	2571	111.1	3355	116.1	2866	111.1
	Zencor +Targa super	2754	119.0	3468	120.0	3044	118.0
	Maton	2441	105.5	2890	100.0	2812	109.0
	Maton +Targa super	2340	101.2	2803	97.0	2712	105.1
Stomp aqua	-	2414	104.3	3030	104.8	2691	104.3
	Basagran	2670	115.4	3439	119.0	2980	115.5
	Pulsar	2867	123.9	3534	122.3	3081	119.4
	Korum	2911	125.8	3610	124.9	3106	120.4
	Zencor	2596	112.2	3381	117.0	2879	111.6
	Zencor +Targa super	2762	119.4	3480	120.4	3057	118.5
	Maton	2462	106.4	2922	101.1	2825	109.5
	Maton +Targa super	2356	101.8	2829	97.9	2712	105.1

LSD. kg.ha^{-1}:

F.A	$p \leq 0.5 = 68$	$p \leq 0.1 = 89$	$p \leq 0.01 = 115$
F.B	$p \leq 0.5 = 78$	$p \leq 0.1 = 103$	$p \leq 0.01 = 132$
F.C	$p \leq 0.5 = 103$	$p \leq 0.1 = 136$	$p \leq 0.01 = 175$
AxB	$p \leq 0.5 = 135$	$p \leq 0.1 = 178$	$p \leq 0.01 = 229$
AxC	$p \leq 0.5 = 179$	$p \leq 0.1 = 236$	$p \leq 0.01 = 304$
BxC	$p \leq 0.5 = 207$	$p \leq 0.1 = 276$	$p \leq 0.01 = 350$
AxBxC	$p \leq 0.5 = 358$	$p \leq 0.1 = 472$	$p \leq 0.01 = 607$

The highest seed yields are obtained by treatment with foliar-applied herbicide Korum after soil-applied herbicide Stomp aqua– 123.7% and by Korum after soil-applied herbicide Dual gold – 123.2% above the untreated control. High yields are obtained also by treatment with foliar-applied herbicide Pulsar after soil-applied herbicides Stomp aqua and Dual gold – 121.8% and 120.9% respectively, as well as by foliar treatment with herbicide tank-mixture Zencor + Targa super after soil-applied herbicides Stomp aqua and Dual gold 119.4% and 119.0% respectively.

Combining the soil-applied herbicides Dual gold and Stomp aqua with the foliar-applied herbicides Basagran, Pulsar, Korum, Zencor and Maton and with the herbicide tank mixtures Zencor + Targa super and Maton + Targa super always results in a higher yield increase compared to the alone use of the respective herbicides and herbicide tank mixtures during the three years of the investigation.

Analysis of variance for grain yield (Table 3) shows that the years have the highest influence on seed yield – 42.8% on the variants. The reason is the large differences in the meteorological conditions during the three years of investigation. The strength of influence of soil-applied herbicides is 4.8% and the strength of influence foliar-applied herbicides is 10.1%. The influence of years, soil-applied herbicides and foliar-applied herbicides is very well proven at $p \leq 0.01$. There is an interaction between soil-applied herbicides and meteorological conditions of years (AxB) – 6.2%, between foliar-applied herbicides and meteorological conditions of years (AxC) – 8.1% and between soil-applied herbicides and foliar-applied herbicides (BxC) – 5.2%. Interactions between soil-applied herbicides and meteorological conditions of years (AxB) and between soil-applied herbicides and foliar-applied herbicides (BxC) are well proven at $p \leq 0.1$. Interaction between foliar-applied herbicides and meteorological conditions of years (AxC) is very well proven at $p \leq 0.01$. There is also interaction between three experiment factors (AxBxC) – 3.3%. It is proven at $p \leq 0.5$.

Based on proven soil-applied herbicide x year interaction, foliar-applied herbicide x year interaction and soil-applied herbicide x foliar-applied herbicide, it was evaluated stability parameters for each herbicide combination between soil-applied herbicide and foliar-applied herbicide for seed yield of winter forage pea with relation to years (Table 4). It was calculated the stability variances σ_i^2 and S_i^2 of Shukla, the ecovalence W_i of Wricke and the stability criterion YS_i of Kang.

Stability variances (σ_i^2 and S_i^2) of Shukla, which recorded respectively linear and nonlinear interactions, unidirectional evaluate the stability of the variants. These variants which showed lower values are considered to be more stable because they interact 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 are regarded as unstable. At the ecovalence W_i of Wricke, the higher are the values of the index, the more unstable is the variant.

On this basis, using the first three parameters of stability, it is found that the most unstable are herbicide Maton and herbicide tank mixture Maton + Targa super, both in their alone use and in their combinations with soil-applied herbicides Stomp aqua and Dual gold. In these variants values of stability variance σ_i^2 and S_i^2 of Shukla and ecovalence W_i of Wricke are the highest and mathematically proven. The reason for this high instability is greater variation in seed yields during years of experience as weather conditions affect those most. In alone use of herbicide Maton and herbicide tank mixture Maton + Targa super without soil-applied herbicide, there is instability from linear and nonlinear types

Table 3. Analysis of variance for seed yield

Source of variation	Degrees of freedom	Sum of squares	Influence of factor, %	Mean squares	Fisher’s criterion	Level of significance
Total	215	436793	100	–	–	–
Tract of land	2	24711	4.5	12372.1	7.0	**
Variants	71	330323	79.9	94220.8	31.2	***
Factor A – Years	2	195870	42.8	77936.0	25.7	***
Factor B –Soil-applied herbicides	2	16862	4.8	4621.3	0.8	**
Factor C –Foliar-applied herbicides	7	53115	10.1	7519.3	3.6	***
AxB	4	6707	6.2	2132.7	0.4	**
AxC	14	22520	8.1	4188.0	0.7	***
BxC	14	63791	5.2	1099.8	0.2	**
AxBxC	32	15626	3.3	434.3	0.1	*
Pooled error	142	79729	15.1	392.1	–	–

*p ≤ 0.5 **p ≤ 0.1 ***p ≤ 0.0

Table 4. Stability parameters of some herbicides, herbicide combinations herbicide tank mixtures for seed yield with relation to years

Herbicides		$\bar{x}$	σ_i^2	S_i^2	W_i	YS_i
Soil-applied	Foliar-applied					
–	–	2595	372.9	353.2	3380.6	-1
	Basagran	2909	217.5	314.3	117.2	6
	Pulsar	3032	205.4	343.7	645.9	8
	Korum	3108	277.7	353.5	961.7	9
	Zencor	2837	210.3	321.0	667.2	5
	Zencor + Targa super	2988	270.6	306.6	888.8	7
	Maton	2615	542.0*	420.2*	4567.8	-1
	Maton + Targa super	2522	603.0*	772.0*	5091.4	-2
Dual gold	–	2679	356.6	381.4	608.9	4
	Basagran	3011	102.4	217.7	555.5	10+
	Pulsar	3137	230.2	111.7	341.3	13+
	Korum	3198	222.1	100.2	345.5	14+
	Zencor	2931	225.7	324.0	566.2	8
	Zencor + Targa super	3089	208.0	303.8	582.4	11+
	Maton	2714	403.3*	317.7	3333.3	0
	Maton + Targa super	2618	442.0*	333.3	4444.4	-1
Stomp aqua	-	2712	224.1	418.6	530.1	5
	Basagran	3030	319.4	312.6	588.1	11+
	Pulsar	3161	283.6	414.8	539.2	13+
	Korum	3209	148.7	363.3	358.6	15+
	Zencor	2952	273.1	465.3	577.4	9
	Zencor + Targa super	3100	249.2	400.4	509.5	12+
	Maton	2736	389.5*	309.6	3000.3	0
	Maton + Targa super	2632	400.4*	364.3	4400.4	-1
Mean		2896				6.4
LSD (p = 0.05)		127				

– proven values σ_i^2 and S_i^2. In combined use of herbicide Maton and herbicide tank mixture Maton + Targa super with soil-applied herbicides Dual gold and Stomp aqua there is instability from linear type – proven values σ_i^2. The values of S_i^2 are not proven. Other herbicides, herbicide combinations and herbicide tank mixtures exhibit high stability because they interact poorly with the conditions of years.

To evaluate the complete efficacy of each tank mixture between soil-applied herbicide and foliar-applied herbicide should be considered as its effect on seed yield of pea and its stability – the reaction of wheat to this variant during the years. Valuable information about the value of technologic value of the variant give the stability criterion YS_i of Kang for simultaneous assessment of yield and stability, based on the reliability of the differences in yield and variance of interaction with the environment. The value of this criterion is experienced that using nonparametric methods and warranted statistical differences we get a summary assessment aligning variants in descending order according to their economic value.

Generalized stability criterion YS_i of Kang, taking into accounts both the stability and value of yields gives negative assessments of untreated control, of herbicide tank mixture Maton + Targa super – with and without soil-applied herbicide and of alone use of herbicide Maton characterizing them as the most unstable and low yields. Combined use of herbicide Maton with soil-applied herbicides gets assessment 0. According to this criterion, technologically the most valuable appears combinations of foliar-applied herbicide Korum with soil-applied herbicides Stomp aqua and Dual gold are technological the most valuable. They are followed by combinations of foliar-applied herbicide Pulsar with soil-applied herbicides Stomp aqua and Dual gold. They combine high levels of seed yield and high stability of this index during the years. From the viewpoint of technology for winter forage pea growing, high ratings also have combinations of herbicide tank mixture Zencor + Targa super with Stomp aqua and Dual gold as well as combinations of foliar-applied herbicide Basagran with the two soil-applied herbicides.

They combine relatively good seed yields with high stability during the years of the investigation. Alone uses of soil-applied herbicides Dual gold and Stomp aqua, of foliar-applied herbicides Basagran, Pulsar, Korum and Zencor, and of herbicide tank mixture Zencor + Targa super have low estimates and them to be avoided. This is due to the absence of effective chemical control against part of weeds and self-sown plants in these variants.

Conclusion

The highest yields of winter forage pea seeds are obtained by treatment with foliar-applied herbicide Korum after soil-applied herbicides Stomp aqua and Dual gold. High yields are obtained also by treatment with foliar-applied herbicide Pulsar after soil-applied herbicides Stomp aqua and Dual gold, as well as by foliar treatment with herbicide tank-mixture Zencor + Targa super after soil-applied herbicides Stomp aqua and Dual gold. Herbicide Maton and herbicide tank mixture Maton + Targa super, both in separated use and in combined use with soil-applied herbicides Dual gold and Stomp aqua are the most unstable for seed yield. Combinations of foliar-applied herbicide Korum with soil-applied herbicides Stomp aqua and Dual gold are technological the most valuable. They are followed by combinations of foliar-applied herbicide Pulsar with soil-applied herbicides Stomp aqua and Dual gold. They combine high seed yield with high stability with relation to different years. Alone uses of soil-applied herbicides Dual gold and Stomp aqua, of foliar-applied herbicides Basagran, Pulsar, Korum and Zencor, and of herbicide tank mixture Zencor + Targa super have low estimates and do not be used. For complete control of all weeds and self-sown plants in winter forage pea crops, two herbicides should be combined – both soil-applied and foliar-applied.

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