Economic analysis of integrated weed management in field bean (*Phaseolus vulgaris* L.)

E. Štefanić[1], I. Štefanić[1], A.J. Murdoch[2]

[1]Faculty of Agriculture, J.J. Strossmayer University, Osijek, Croatia
[2]Department of Agriculture, University of Reading, United Kingdom

ABSTRACT

Field experiments were conducted in field bean in the north-eastern part of the Republic of Croatia to compare weed control and crop response under different management practices within the critical period of field bean production. The practices consisted in broadcast application of labelled rate of preemergence herbicide (PRE) and postemergence herbicide application: (POST) broadcast, band application over the rows, and band application combined with mechanical cultivation using of different herbicide doses recommended by the manufacturer (2×, 1×, 1/2×, 1/4×, 1/8×). In 1999, weed control with PRE application of pendimethalin was superior to POST bentazone application due to late emergence of weeds and lack of residual herbicide control. In 2000 bentazone combined with cycloxydim controlled weeds in field bean better than PRE herbicide application. Based on the results of this research, single PRE or POST application of herbicide did not control a broad spectrum of weeds and did not provide the commercially acceptable full season control. Reduced rates of herbicide are not advisable under high weed pressure.

Keywords: field bean; integrated weed management; reduced rate technology; economic analysis

In some European countries legislation requires that the amount of used pesticide should be reduced by a defined percentage within a certain number of years. The Republic of Croatia does not have any regulation yet, but there is a great public concern to reduce herbicide use for both environmental and economic reasons. To achieve this aim, it is necessary to have a good understanding of the effect of weeds on the crop yield and on the level of weed infestation that is likely to arise in the next year.

Production of field bean depends on herbicide applications very much, and broadcast applications of doses recommended by the manufacturer are a worldwide practice (Wilson et al. 1980, Renner and Powell 1992, Urwin et al. 1996). However, the design of integrated weed management (IWM) is essential in order to reduce the use of herbicides for crop production. Interest in integrated weed management in field bean is growing. Numerous experiments in other crops evaluated the influence of tillage systems, cultivar choice, row spacing, and crop density on weed competitiveness (Malik et al. 1993, Sandoval-Avila et al. 1994, Bostrom 1999).

Moreover, it is well known that weeds must be removed from row crops before they begin to reduce crop yield. Research shows that there is a limited period of time after crop emergence when weeds can grow in field bean without reducing yield (Dawnson 1964, Wooley et al. 1993, Stefanic et al. 1999). An alternative weed management system must either destroy weeds or suppress them long enough enabling field beans to receive a competitive advantage and weeds will not then reduce the yield.

Information emerging from a large number of individual studies generally supports the idea of using herbicides at below-labelled rates. By combining different management practices, herbicides may be used at lower doses than normally recommended, while still maintaining acceptable weed population levels. Reduced rate technology is an approach to minimise herbicide use and reduce management costs (DeFelice et al. 1989, Devlin et al. 1991, Vangessel and Westra 1997). Profitable, alternative weed management systems are therefore needed to help farmers to solve this pressing environmental concern without greatly changing current farming practice. However, despite of many successful examples (Buhler et al. 1995, Zoschke 1994), concern over the use of herbicides at below-labelled rates remains (Bussan et al. 2000, Zhang et al. 2000).

The objective of this research was to evaluate economics of weed control and field bean response to PRE broadcast herbicide application and POST application through broadcasting, banding and banding combined with between row cultivation using reduced herbicide rates. This information is needed to employ a more integrated weed management strategy for field bean production in the Republic of Croatia that reduces herbicide inputs.

MATERIAL AND METHODS

Field experiments were carried out in 1999 and 2000 at Osijek-Baranja County. They were established at two lo-

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Table 1. Experimental scheme

Treatment	Dose of herbicide					
	2×	1×	1/2×	1/4×	1/8×	0
PRE (broadcast)		•				
POST (broadcast)	•	•	•	•	•	
POST (band)	•	•	•	•	•	
POST (band + mechanical)	•	•	•	•	•	•
Control						•

calities: Ivanovci and Tenja. Field bean cv. Slavonski zeleni (bush growth habit) was sown each year after corn (*Zea mays* L.) in first decade of May in 50cm rows to achieve a population of 200 000 plants/ha. A randomised block design with four replications was established in areas highly infested with natural weed populations. Individual plots measured 5 by 2.5 m.

In the first year of the experiment pendimethalin was applied preemergence (PRE) at 4 kg ai/ha soon after planting, and bentazone was applied postemergence (POST) at 3 kg ai/ha when germinated bean plants mostly had two developed 3-leaves as recommended. Pendimethalin was applied to the whole plot area at a recommended dose while bentazone was applied at a different dose (Table 1) to the whole plot area and also in bands over the 50cm wide crop rows. Mechanical interrow cultivation with different dose of POST applied herbicide banding over crop rows was also included in the experiment. Mechanical interrow cultivation was done at an early stage of the crop (27 and 26 DAS, respectively). The second year of the experiment followed the same scheme but prometryn was applied PRE at 3 kg ai/ha, and bentazone was combined with cycloxydim (3 + 3 kg ai/ha) to control rapidly emerging Johnson grass (*Sorghum halepense*) on the experimental area.

Naturally occurring weed populations were recorded at the end of bean vegetation after the effect of herbicides had become evident by randomly placing a 50 by 50cm quadrats four times on each plot. Weeds were cut at the ground level, separated by species, counted, oven dried at 80°C for 4 d and weighed.

Harvest was carried out when the crop reached maturity. Seed yields were adjusted to 14% moisture and yield from each plot was expressed as g per m^2. Ten randomly selected bean plants from the central part of each plot were hand harvested in both years to obtain yield components (number of pods, number of seeds per pod).

Weed control data from different weed strategy options at labelled herbicide rate: PRE (broadcast), POST (broadcast), POST (band), POST (band + mechanical), bean yield and yield components were analysed by analysis of variance. Total weed density and weed biomass data were log transformed prior to the analysis, but only the untransformed data are reported. Treatments were separated by Fisher's Protected *LSD* test at $\alpha \geq 0.05$ (Steel and Torrie 1980). In addition, linear regression analyses were made to test the relation between weed density and biomass treated with different herbicide doses (2×, 1×, 1/2×, 1/4×, 1/8×) of post applied bentazone band over the rows, broadcast or band combined with mechanical cultivation. Due to a significant treatment by year interaction, years were analysed separately. All data were analysed using SAS GLM procedure (SAS Inst. 1988).

To evaluate a short-term economic effect Gross Margins were calculated for each weed control strategy with doses recommended by the manufacturer and additionally with sublethal dose. Gross Margin was calculated for each treatment by subtracting the cost of production from the crop value at harvest. Yields of field beans were expressed as kg/ha for this purpose.

Table 2. Total weed density (nb/m^2) and dry weight (g/m^2) in field bean in the harvest period in 1999 and 2000

Treatments	1999		2000	
	density	biomass	density	biomass
PRE (broadcast)	29.0 b	54.37 b	28.7 ab	315.12 a
POST (broadcast)	73.0 ab	542.03 a	6.7 b	32.78 b
POST (band)	85.0 ab	576.12 a	7.5 b	32.61 b
POST (band + mechanical)	180.3 a	576.49 a	11.0 b	51.81 b
Control	97.8 ab	500.26 a	32.5 a	76.46 b

* means within a column followed by the same letter are not significantly different at the 0.05 probability level using Fisher's Protected *LSD* test

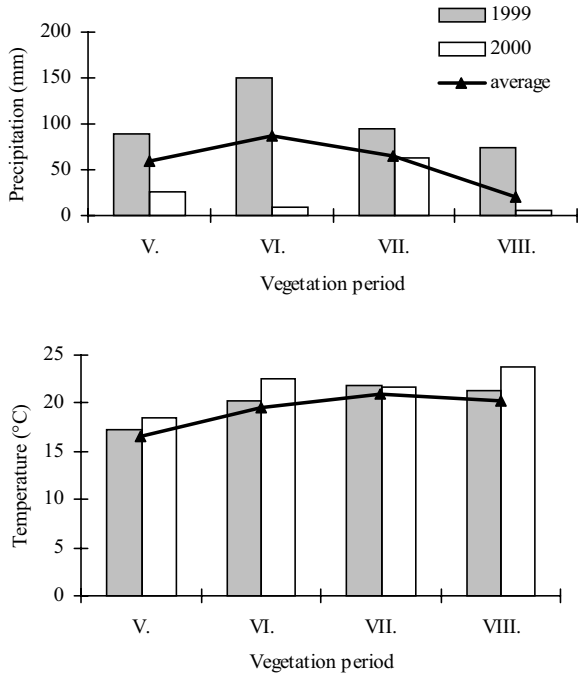


Figure 1. Average monthly precipitation and air temperature during the growing season 1999 and 2000, and long-term (1961–2000) average monthly precipitation and average air temperature

RESULTS AND DISCUSSION

Weeds present

In the first year of experiment (1999) the field site was dominated by common lamb's-quarters (*Chenopodium album* L.). Moreover, common lamb's-quarters represented 68% of total weed biomass at the end of vegetation. This annual broadleaf weed started to germinate simultaneously with the crop. Development of this species was delayed only on plots with pre-emergence applied pendimethalin, and it resulted in significantly lower density and aboveground biomass compared to all other plots in the experiment (data not shown).

In the second year (2000) sixteen weed species were present on the studied plot but none of them dominated at the site like common lamb's-quarters in the previous year. Among them prevalent weed species were Johnson grass (*Sorghum halepense*), common lamb's-quarters (*Chenopodium album*), black nightshade (*Solanum nigrum*), tuberous sweet pea (*Lathyrus tuberosus*) and common ragweed (*Ambrosia artemisiifolia*).

Weed management

Preemergence broadcast applied pendimethalin represented the best option of weed control in 1999 (Table 2). This treatment significantly reduced total weed density and weed biomass. Other treatments failed to provide satisfactory weed control, especially of dominant common lamb's-quarters. All the postemergence applied herbicide treatments did not reduce weed density and biomass compared to control (Table 2). Taking into consideration that 1999 was an extremely wet year (Figure 1) the efficacy of POST applied herbicides seems to be very low even with 2× dose. Common lamb's-quarters escaped herbicide control, developed huge aboveground biomass totally covering bean plants. Moreover, when bean plants were between one and two developed 3-leaves, and POST application was recommended, common lamb's-quarters plants succeeded to reach about 20–25 cm height and probably were not susceptible to herbicide application. However, postemergence weed control failure in 1999 resulted consequently in a significant yield reduction (Table 3).

No significant differences were observed between post broadcast application and spraying over the field beans rows in total weed density, biomass and field bean yield (Tables 2 and 3). Unfortunately, compared to control, untreated plots, the efficacy of post herbicide application was extremely low.

One single cultivation treatment between field bean rows combined with POST herbicide applied in a band over the field bean rows did not provide the expected weed control. Mechanical cultivation was done during the critical period of field bean production (Stefanic et al.

Table 3. Bean yield (g/m^2), pods per plant and seeds per pod (based on 10 randomly selected plants) as influenced by weed infestation

Treatments	1999			2000		
	bean yield	pods per plant	seeds per pod	bean yield	pods per plant	seeds per pod
PRE (broadcast)	251.0 a	9.4 a	2.4 ns	32.3 ns	1.5 ns	0.5 b
POST (broadcast)	64.9 b	2.3 b	2.0 ns	52.4 ns	1.9 ns	1.4 a
POST (band)	67.7 b	2.7 b	1.9 ns	66.2 ns	2.1 ns	0.6 b
POST (band + mechanical)	123.1 b	4.7 b	2.3 ns	50.0 ns	3.7 ns	1.1 ab
Control	58.2 b	1.9 b	1.7 ns	28.3 ns	2.0 ns	0.8 b

* means within a column followed by the same letter are not significantly different at the 0.05 probability level using Fisher's Protected *LSD* test

Table 4. Linear regression coefficients for weed density and weed biomass regressed against applied herbicide doses for the year 2000

	Weed density			Weed biomass		
	slope	intercept	R^2	slope	intercept	R^2
Broadcast	0.137	0.561	0.247	0.211	1.037	0.376
	(0.057)	(0.188)		(0.064)	(0.213)	
Band	0.104	0.693	0.437	0.091	1.382	0.213
	(0.028)	(0.092)		(0.041)	(0.136)	
Band + mechanical	0.118	0.772	0.367	0.191	1.250	0.392
	(0.118)	(0.121)		(0.056)	(0.185)	

Standard errors are given in brackets; fitted lines are shown in Figure 2

1999). Very high average number of weeds per square meter in 1999 (180.3 nb/m^2) was a result of serious infestation with yellow foxtail (*Setaria glauca* L.) in this part of experimental area, but average total weed dry biomass in band + mechanical treatment (576.49 g/m^2) did not significantly differ from other POST treatments and control (Table 2). Therefore it is not enough to remove between-row weeds only once per vegetation because weeds can then have enough time to regrow and to cover the surface as much as in the untreated weedy checks. Or, mechanical cultivation should be done later in the season. Additional research is required to distinguish between these possibilities although as observed in previous research (Buhler et al. 1992), one cultivation treatment controlled 60% of common lamb's-quarters in soybean. Although no significant difference in weed density and biomass per square meter exists in different POST treatments, field bean yield and bean components (Table 3) increased in 1999.

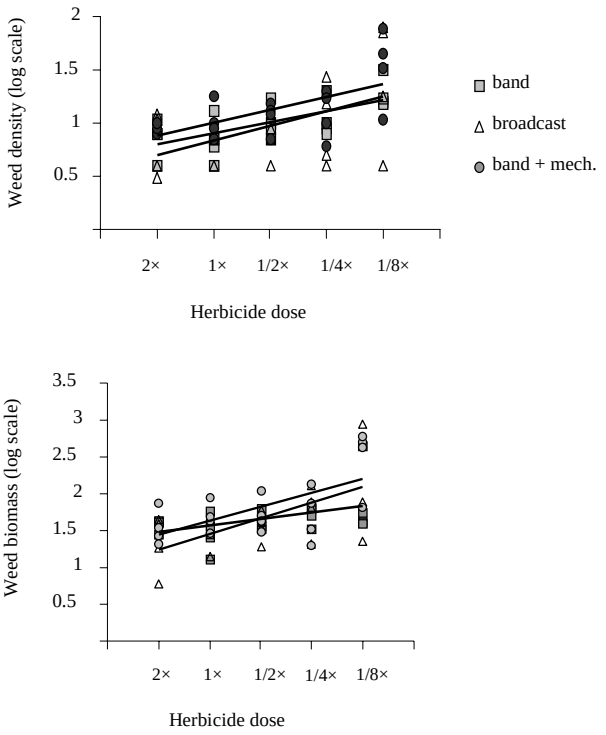


Figure 2. Weed density and weed dry weight on the whole plot spray, band spray and band spray + mechanical cultivation graphed versus applied herbicide doses for the year 2000

Extremely dry weather conditions during the second year of experiment significantly reduced weed density and biomass compared to the previous year (Table 2). Rainfall deficit during the sowing period did not activate preemergence herbicide application and resulted in significantly higher weed density and aboveground biomass especially for Johnson grass (data not shown). Postemergence application of bentazone and cycloxydim significantly reduced the number and biomass of weeds present (79.4% and 57.13%, respectively) compared to control. However, there is no significant difference between full rate broadcast application and banding over field bean rows. Even though in the previous year total weed density and biomass were significantly higher compared to extremely dry year 2000, a similar pattern appears. No significant difference was found in both years for weed density, biomass and bean yield between broadcast and band application of POST herbicide.

Therefore, banding the chemical application over the crop rows resulted in 50% herbicide reduction because only 50% of the field area was sprayed. The results of this paper could suggest that it is not necessary to spray the whole field area in field beans production. However, a number of other factors should be considered before a conclusion is drawn for recommendation to farmers; for example, the influence of competition, weeds present in some fields, crop shedding and type of chemical application. Herbicide reduction always implies a threat of increased competition from weeds caused by a higher weed plant survival and increased seed production by surviving weeds (Legere et al. 1996) as we confirmed in our experiment.

Integration of interrow cultivation with banding of herbicide full rate over the crop rows did not ensure weed control and did not provide satisfactory bean yield in both years, as expected, although Buhler et al. (1992) and Donald (2000) demonstrated satisfactory weed control by band herbicide application over soybean rows combined with mechanical interrow cultivation.

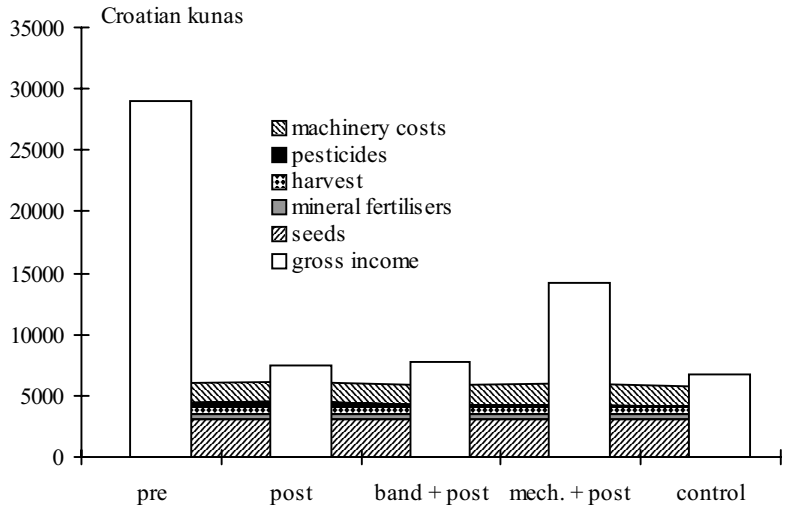


Figure 3. Short-term economic analysis of various weed management practices in field bean, 1999

Below labelled rates of herbicides

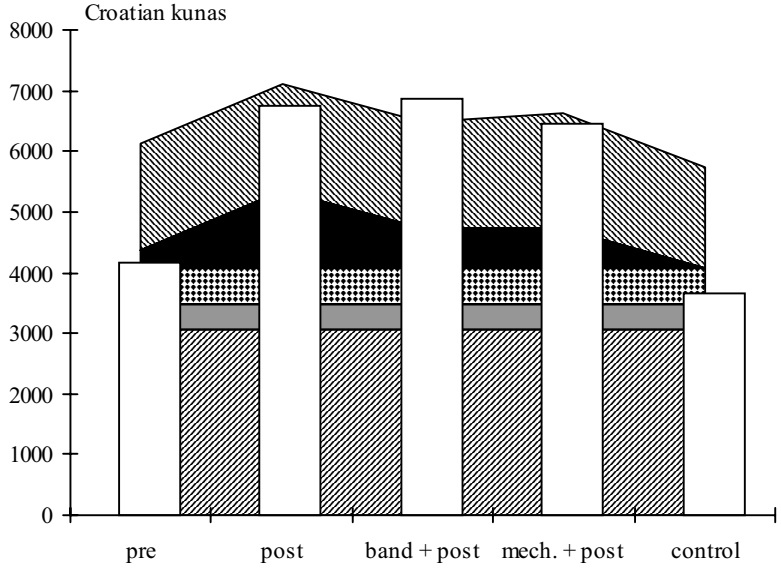
The use of sublethal herbicide dose could be promising as a strategy for decreasing the production costs and for environmental reasons, but results from other experiments indicate that this effect varies greatly, depending on the used herbicides and amount of weed species present in the fields (Bussan et al. 2000, Zhang et al. 2000). Results from the second year of our investigations are presented in Table 4 and Figure 2. Data on different herbicide doses from the first year of experiments were excluded from the analysis because of a complete failure of POST treatments.

Although coefficients of determination (Table 4) are very low for all, broadcast, band and band + mechanical treatments, intercepts indicate that weed density and its associated dry biomass are too high even in treatments with double dose herbicides.

Field bean yield and economic analysis

Bean yield was significantly influenced by weeds and weather conditions (Table 2, Figure 1). Unfavourable weather conditions in the second year of experiment resulted in very poor bean yield and yield quality (Table 3). The best bean yield was obtained by PRE (broadcast) treatment during the first year of experiment, when pendimethalin controlled weeds on the experimental plots for a satisfactorily long time. Similar low density and biomass of weeds was noticed in the next year on plots with POST emergence herbicide application, but drought seriously reduced field bean yield.

The economic analysis considered cost of production (Figures 3 and 4). At the time when the experiment was carried out, there were no subsidies for bean production in the Republic of Croatia and gross income is calculated from the yield value at harvest. Since costs of seeds,



Some weed control strategies did not cover production costs as a total. If any particular cost appears in the figure as not covered by gross income, it has no significance and it is caused only by the order of data series.

Exchange rate for Croatian kuna:
August 1999 – 1 $ = 7.13 kn,
August 2000 – 1 $ = 8.22 kn

Figure 4. Short-term economic analysis of various weed management practices in field bean, 2000 (For explanations see Figure 3)

Table 5. Influence of different herbicide doses on economic results in field bean production, 2000 (Gross Margin expressed in Croatian kunas)

POST	Broadcast		Band		Band + mechanical	
Herbicide dose	yield (kg/ha)	Gross Margin	yield (kg/ha)	Gross Margin	yield (kg/ha)	Gross Margin
2×	548	–1347	374	–2296	448	–1503
1×	524	–363	533	400	500	–186
1/2×	438	–824	418	–759	633	1851
1/4×	404	–939	317	–1899	571	1214
1/8×	114	–4516	280	–2295	552	1050

mineral fertilisers and harvest are the same for all treatments, Gross Margin is affected by costs of pesticides, machinery costs and certainly yield influenced by various weed control strategies.

Economic analysis of bean production in 1999 shows that all treatments generated Gross Margin. However, strategies with POST herbicide application (excluding POST spraying combined with mechanical weed control) generated symbolic Gross Margin and were neither competitive nor attractive to be adopted by farmers. Costs of chemicals and machinery were very similar and differences in Gross Margin were caused mainly by yield. In the end, treatment with PRE-emergence spraying was the best option in terms of money.

The results in 2000 had a different pattern. Due to the grass weed infestation noticed during the field bean emergence, POST treatments required the use of additional herbicides to control rapidly emerging Johnson grass on the whole experimental area and drove the costs of production up. In spite of that, yields were very low and gross income made just symbolic Gross Margin (band POST spraying) or did not cover even production costs (remaining four treatments).

Reducing the herbicide dose is one of the ways to cut the costs and diminish the negative impact on the environment (Table 5). Broadcast POST spraying in field bean with double dose caused phytotoxic injury and significant Gross Margin reduction. Moreover, sublethal doses did not control the weed population adequately and decreased yields were a reason for smaller Gross Margin. Banding the herbicides over the crop rows decreased the amount of used herbicide by 50%. However, the pattern of Gross Margin change was the same like in broadcast POST spraying and the recommended herbicide dose was the only treatment with positive Gross Margin. Combination of mechanical cultivation with band POST spraying gave a different result. Although a double herbicide dose caused phytotoxic injury (and decreased Gross Margin), reduced herbicide doses did not decrease yields. These yields combined with savings in herbicide expenses were a reason for the improved financial result of field bean production.

Integrated weed management is an important issue in modern agriculture and one of the goals in agricultural policy of the Republic of Croatia. Agriculture is under constant pressure to improve in ecological and economic sense. To adopt reduction in tillage and herbicide use it is necessary to have weeds controlled successfully over a longer period of time as a tool to suppress the weed seed bank. Agriculture in north-eastern Croatia was not unfortunately able to cultivate a significant proportion of arable land during the past ten years. Due to the war operations and laid land mines weed infestation significantly increased. Insisting on reduction of herbicide use without reliable information on previous weed infestation could be harmful in the long run.

Environmental conditions, weed density, species, and emergence patterns as well as timeliness of control practice influence the effectiveness of weed control strategy. Based on the results of this research, switching from chemically intensive to integrated weed management system is not advisable under the high weed pressure.

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ABSTRAKT

Ekonomická analýza integrované ochrany proti plevelům u fazolu obecného (*Phaseolus vulgaris* L.)

Polní pokusy s fazolem obecným zaměřené na hubení plevelů a následnou reakci plodin jsme uskutečnili v severovýchodní části Chorvatské republiky s použitím různých způsobů ochrany proti plevelům v kritickém období produkce fazolu obecného. Opatření spočívala v celoplošné preemergentní aplikaci (PRE) dané dávky herbicidu a v postemergentní aplikaci herbicidu (POST): celoplošně, pásová aplikace nad řádky a kombinace pásové aplikace s mechanickou kultivací při použití různé dávky herbicidu doporučené výrobcem (2×, 1×, 1/2×, 1/4×, 1/8×). V roce 1999 bylo hubení plevelů pomocí aplikace pendimethalinu PRE účinnější než aplikace bentazonu POST v důsledku pozdějšího vzcházení plevelů a absence účinku reziduálního herbicidu. V roce 2000 bentazon v kombinaci s cycloxydimem působil v porostu fazolu obecného účinněji než aplikace herbicidu PRE. Na základě získaných výsledků lze učinit závěr, že jedna aplikace herbicidu PRE nebo POST nevede k likvidaci širokého spektra plevelů a nezajišťuje ekonomicky přijatelné hubení plevelů po celou sezonu. Při vysokém zaplevelení nelze doporučit snížené dávky herbicidů.

Klíčová slova: fazol obecný; integrovaná ochrana proti plevelům; technologie snížené dávky; ekonomická analýza

Corresponding author:

Prof. Dr. Sc. Edita Štefanić, Faculty of Agriculture, J.J. Strossmayer University, Trg Svetog Trojstva 3, 31000 Osijek, Croatia
tel.: + 385 31 224 287, fax: + 385 31 207 017, e-mail: sedita@suncokret.pfos.hr