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Technical effectiveness and economic return of the glyphosate-resistant hairy fleabane management in soybean pre-emergence[1]

Eficiência técnica e retorno econômico do manejo de buva resistente ao glyphosate em pré-emergência da soja

Cristiano Piasecki[2]; Marcos Ivan Bilibio[3]; Joanei Cechin[2]; Maicon Fernando Schmitz[4]; Jonas Rodrigo Henckes[4]; Leandro Oliveira da Costa[5]

Abstract - The commercial release of the Roundup Ready® soybean helped the management of weeds and allowed the application of glyphosate during the post-emergence of the culture. However, the intensive use of this herbicide selected resistant hairy fleabane biotypes and hindered control. Many works evaluate the technical effectiveness of herbicides, however, most of the times; the economic return is not analyzed when making decisions about the choice of which herbicide to apply. The aim of this work was to evaluate the technical effectiveness and the economic return of applying herbicide associations and rates in the management of glyphosate-resistant hairy fleabane, in soybean pre-emergence. The experiment was carried out in randomized block design with four replicates. Treatments consisted in associations among glyphosate, 2.4-D, saflufenacil, diclosulam, chlorimuron-ethyl and flumioxazin. The analyzed variables were hairy fleabane control and phytotoxicity on soybean on 7, 14, 21 and 35 days after the application and yield of soybean. The economic return of treatments was calculated according to the cost of the herbicides and the soybean yield. Results about control and yield shows that the association of glyphosate, chlorimuron-ethyl, flumioxazin and 2.4-D and of glyphosate, chlorimuron-ethyl, 2.4-D and saflufenacil presented the best technical effectiveness response and the use of glyphosate, chlorimuron-ethyl and 2.4-D presented the best economic return. However, the increase in chlorimuron-ethyl rates and its association with flumioxazin did not improve the control of hairy fleabane.
Keywords: *Conyza* spp.; control; cost; herbicide association

Resumo - A liberação comercial da soja *Roundup Ready*® favoreceu o manejo de plantas daninhas e possibilitou o cultivo da soja RR® e a aplicação do glyphosate em pós-emergência da cultura. No entanto, o uso intensivo deste herbicida selecionou biótipos de buva resistentes e dificultou o controle. Muitos trabalhos avaliam a eficiência técnica de herbicidas, porém, na maioria das vezes, o retorno econômico não é analisado na tomada de decisão sobre a escolha dos

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[2] Doutorando no Programa de Pós-Graduação em Fitossanidade pela Universidade Federal de Pelotas (PPGFS/UFPel), Pelotas, Rio Grande do Sul, Brasil. E-mail: <c_piasecki@hotmail.com>.
[3] Mestrando em Agronomia pela Universidade de Passo Fundo (PPGAgro/UPF), Passo Fundo, Rio Grande do Sul, Brasil.
[4] Mestrando no Programa de Pós-Graduação em Fitossanidade pela Universidade Federal de Pelotas (PPGFS/UFPel), Pelotas, Rio Grande do Sul, Brasil.
[5] Doutorando em Agronomia pela Universidade de Passo Fundo (PPGAgro/UPF), professor no Instituto Federal Farroupilha (IFFAR), Campus Júlio de Castilhos, Rio Grande do Sul, Brasil.

herbicidas a serem aplicados. O objetivo do trabalho foi avaliar a eficiência técnica e o retorno econômico da aplicação de associações e doses de herbicidas no manejo de buva resistente ao glyphosate em pré-emergência da soja. O experimento foi conduzido à campo no delineamento de blocos ao acaso com quatro repetições. Os tratamentos consistiram de associações entre glyphosate, 2,4-D, saflufenacil, diclosulam, chlorimuron-ethyl e flumioxazin. As variáveis analisadas foram controle de buva e fitotoxicidade na soja aos 7, 14, 21 e 35 dias após a aplicação e o rendimento de grãos da soja. O retorno econômico dos tratamentos foi calculado em função do custo dos herbicidas e do rendimento de grãos da soja. Os resultados de controle e rendimento demonstraram que a associação de glyphosate, chlorimuron-ethyl, flumioxazin e 2,4-D e, glyphosate, chlorimuron-ethyl, 2,4-D e saflufenacil apresentaram as melhores respostas de eficiência técnica e, a aplicação do glyphosate, chlorimuron-ethyl e 2,4-D apresentou o melhor retorno econômico. Entretanto, o aumento nas doses de chlorimuron-ethyl e sua associação com flumioxazin não melhorou o controle da buva.
Palavras-chaves: *Conyza* spp.; controle; custo; associação de herbicidas

Introduction

Soybean is the most important oleaginous crop cultivated in the world. Brazil is the second largest grower and the main exporter, with about 95.4 million tons produced (Conab, 2017). In the Southern, Southeastern and Central-Western regions of Brazil, the glyphosate-resistant hairy fleabane (*Conyza bonariensis*, *C. sumatrensis* and *C. canadensis*) is considered one of the main weeds in soybean crops, with a potential to cause yield losses up to 40% (Trezzi et al., 2013). In addition, this weed development is favored in no-tillage systems, which is an important system in Brazil (Lazaroto et al., 2008; Lamego et al., 2013).

After the commercial release of the Roundup Ready® (RR®) technology, which gave tolerance to glyphosate on soybean, in 1998 (CTNBio, 1998) the weed management was changed by the replacement of herbicides combinations through the only active ingredient, the glyphosate (Gazziero, 2005). However, the incorrect use of this herbicide selected resistant biotypes, and the first case of hairy fleabane resistance was confirmed in Brazil in the 2004/2005 season (Vargas et al., 2007). In order to manage glyphosate-resistant (GR) hairy fleabane it is essential to adopt practices that aim the reduction of the emergence of the weeds (Evans et al., 2016), and control them at initial development stages. Thus, the application of herbicides with different modes of action is an effective and low cost tool to manage resistant biotypes (Dalazen et al., 2015a), and it contributes to the reduction of the negative interference of hairy fleabane on soybean (Oliveira Neto et al., 2010).

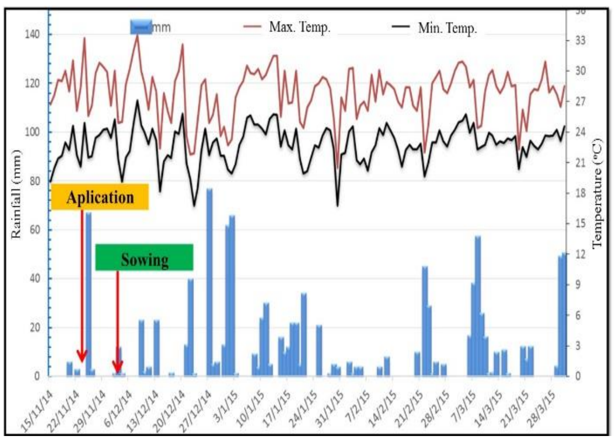
In most situations, making decisions in order to control weeds takes into consideration only the technical effectiveness, without considering the provided economic return (Vazquez et al., 2014). In the current agricultural scenario, where production costs are high, the rational use of materials may help improving the final profitability of the growers. Therefore, it is essential to evaluate the technical effectiveness in controlling weeds and the economic return, taking into consideration factors such as cost of the used herbicides, provided control and culture yield (Faria et al., 2010).

Studies about the management of weeds that relate technical effectiveness and economic return in different cultures are essentials and may help growers and technicians in making better decisions. The aim of this work was to evaluate the technical effectiveness and the economic return of applying herbicide associations and rates in the management of glyphosate-resistant hairy fleabane, during the pre-emergence of soybean.

Material and Methods

The experiment was conducted on the field during the 2014/2015 season, in an experimental area of typical dystrophic Red Latosol (Embrapa, 2013), with a no-till system, in an area with crop residues of black oat and ryegrass controlled 30 days before soybean sowing (DAS) with clethodim 76.2 g ha^{-1} and glyphosate 720 g ha^{-1} a.e. ha^{-1}, aiming at the selection of glyphosate-resistant hairy fleabane populations.

The climate information during the time that the experiment was conducted is presented in Figure 1.



Source: SOMAR meteorology.

Figure 1. Climate information about Passo Fundo, Rio Grande do Sul state, in the period between November 2014 to March 2015.

The experimental design was randomized blocks with four replications, in experimental units of 15 m^2 (3.0 x 5 m). The used soybean cultivar was BMX Vanguarda RR®, sowed at the distance of 50 cm between the rows; the other culture tracts were performed according to the technical recommendations for soybean (Embrapa, 2014).

Treatments consisted in the association of different rates and herbicides during the pre-emergence of soybean, recommended for the management of hairy fleabane, as follows: glyphosate (Roundup Original® CS, 360 g a.e. L^{-1}, Monsanto); chlorimuron-ethyl (Classic® WG 250 g a.i. kg^{-1}, DuPont); flumioxazin (Flumyzin® WP, 500 g a.i. kg^{-1}, Ihara); 2.4-D amina (DMA® 806 BR, 670 g a.e. L^{-1}, Dow AgroSciences); saflufenacil (Heat® WG, 700 g a.i. kg^{-1}, Basf); diclosulam (Spider® 840 WG, 840 g a.i. kg^{-1}, Dow AgroSciences) (Table 1). For evaluation purposes, two control samples were maintained, one of them was free from weeds and other one with weeds, that is, weeded control sample and infested control sample, respectively.

Treatments application occurred on 10 DBS (days before sowing), and it was performed with a CO_2 pressurized backpack sprayer, using 110.02 fan type nozzles, spaced 50 cm apart; the equipment was calibrated to spray a volume of 150 L ha^{-1}. The average temperature during the application was 28.3 °C, U.R. 74% and wind speed 5.2 m/s. At the time of the application, the experimental area presented an average infestation of six glyphosate-resistant hairy fleabane plants m^{-2} less than 15 cm high (Figure 2).

The analyzed variables were hairy fleabane visual control (%), phytotoxicity (%) and soybean yield (technical effectiveness), cost evaluation, economic return analysis (ER) and relative economic return analysis (RER) of the treatments. The visual evaluation of hairy fleabane control was performed on days 7, 14, 21 and 35 after application (DAA), and the phytotoxicity on days 7 and 14 after soybean emergence (DAE), using a percentage scale where zero refers to the absence of control/phytotoxicity and 100 refers to the complete death of plants (SBCPD, 1995).

The soybean yield was determined through the harvest of five meters from the three central line of each plot (usable area of 7.5 m^2). After harvesting, the material was tracked, weighed and the humidity of the kernels was determined. After correcting the humidity to 13%, the grain yield was calculated in kg per hectare.

Table 1. Herbicides and rates used to control glyphosate-resistant hairy fleabane in pre-emergence of RR® soybean. Passo Fundo (RS), 2014/2015.

	Treatments*	Rates - g a.i. or a.e. ha^{-1}
T1	Glyphosate[1] + chlorimuron-ethyl[2] + flumioxazin[3]	1080 + 17.5 + 51
T2	Glyphosate + chlorimuron-ethyl + flumioxazin	1080 + 20 + 58.5
T3	Glyphosate + chlorimuron-ethyl + flumioxazin	1080 + 22.5 + 65.6
T4	Glyphosate + chlorimuron-ethyl + flumioxazin	1080 + 25 + 73
T5	Glyphosate + chlorimuron-ethyl + flumioxazin	1080 + 30 + 87.5
T6	Glyphosate + chlorimuron-ethyl + flumioxazin + 2,4-D[4]	1080 + 17.5 + 51 + 670
T7	Glyphosate + chlorimuron-ethyl + flumioxazin + 2.4-D	1080 + 20 + 58.5 + 670
T8	Glyphosate + chlorimuron-ethyl + flumioxazin + 2.4-D	1080 + 22.5 + 65.6 + 670
T9	Glyphosate + chlorimuron-ethyl + flumioxazin + 2.4-D	1080 + 25 + 73 + 670
T10	Glyphosate + chlorimuron-ethyl + flumioxazin + 2.4-D	1080 + 30 + 87.5 + 670
T11	Glyphosate + chlorimuron-ethyl + flumioxazin + 2.4-D	1080 + 50 + 50 + 670
T12	Glyphosate + chlorimuron-ethyl + 2.4-D	1080 + 22,5 + 670
T13	Glyphosate + chlorimuron-ethyl + 2.4-D + saflufenacil[5]	1080 + 25 + 670 + 50
T14	Glyphosate + flumioxazin + 2.4-D	1080 + 65.6 + 670
T15	Glyphosate + diclosulam[6] + 2.4-D	1080 + 25.2 + 670
T16	Glyphosate + 2.4-D	1080 + 670
T17	Weeded control sample	-
T18	Infested control sample	-

[1] Roundup Original® CS (360 g a.e. L^{-1}, Monsanto); [2] Classic® WG (250 g a.i. kg^{-1}, DuPont); [3] Flumyzin® WP (500 g a.i. kg^{-1}, Ihara); [4] DMA® 806 BR (670 g a.e. L^{-1}, Dow AgroSciences); [5] Heat® WG (700 g a.i. kg^{-1}, Basf); [6] Spider® 840 WG (840 g a.i. kg^{-1}, Dow AgroSciences). * An adjuvant was added according to the recommendation of the herbicide manufacture.

Credit: Rodrigo Borkowski Rodrigues.

Figure 2. Picture of the experimental area on the day of treatment application. Passo Fundo (RS), 2014.

The cost of treatments was established based on the survey about the average prices used by 10 agricultural cooperatives from the state of Rio Grande do Sul, between January and September 2016. The considered price of soybean was R$ 68.50 bag^{-1} (60 kg). The economic return (ER) demonstrates the net profit of the yield (bags ha^{-1}) of the herbicide treatment (T_H) in relation to the infested control sample; this value is subtracted by the cost of the herbicide (bags ha^{-1}) (Equation 1). On the other hand, the relative economic return (RER) expresses the yield profit (bags ha^{-1}) for each soybean bag or kilogram invested in control, calculated according to the (Equation 2).

Equation 1:

$$ER = (T_H \text{ yield} - \text{Infested control sample yield}) - T_H \text{ cost}$$

Equation 2:

$$RER = (T_H \text{ yield} - \text{Infested control sample yield}) - T_H \text{ cost}$$

Data about control, phytotoxicity and yield were analyzed as for normality (Shapiro-Wilk test) and homoscedasticity (Hartley test); then, they were submitted to analysis of variance by F test at 5% probability. When significant, the averages were grouped by Scott-Knott test ($p \leq 0.05$). Yield data were analyzed by

Dunnett test (p≤0.05) and compared with the weeded control sample.

Results and Discussion

The obtained phytotoxicity values were lower than 5% and did not present any statistical difference by analysis of variance (data not presented), which allows inferring that soybean is selective to the studied herbicides, in rates and periods. While evaluating the effect of treatments in controlling hairy fleabane and in the soybean yield, a significant statistical difference was highlighted among the treatments. The best control and soybean yield were obtained in the association of the herbicides glyphosate, chlorimuron-ethyl, 2,4-D and saflufenacil (T13), and glyphosate associated to chlorimuron-ethyl, flumioxazin and 2,4-D (T7), respectively, not differing from the weeded control sample (T17). However, the increase in rates of chlorimuron-ethyl and flumioxazin associated to glyphosate did not result in a significant increase in hairy fleabane control and did not provide any increase in soybean yield (Table 2).

Table 2. Control of glyphosate-resistant hairy fleabane and soybean yield according to the applied herbicides in RR® soybean pre-emergence. Passo Fundo (RS), 2014/2015.

	Treatments	Hairy Fleabane control (%)				Yield (kg ha^{-1})
		7 DAA	14 DAA	21 DAA	35 DAA	
T1	Gly+chl+flu (1080+17.5+51)	38 d*	55 e*	61 d*	65 e*	ns3683.2 b*
T2	Gly+chl+flu (1080+20+58.5)	53 c	65 d	62 d	68 e	ns3601.9 b
T3	Gly+chl+flu (1080+22.5+65.6)	58 c	60 d	68 d	73 d	ns3703.4 b
T4	Gly+chl+flu (1080+25+73)	53 c	63 d	66 d	69 e	ns3721.4 b
T5	Gly+chl+flu (1080+30+87.5)	68 b	65 d	66 d	75 d	ns3701.4 b
T6	Gly+chl+flu+2.4-D (1080+17.5+51+670)	58 c	75 c	78 c	80 c	**3562.9 c
T7	Gly+chl+flu+2,4-D (1080+20+58.5+670)	58 c	75 c	78 c	81 c	ns3796.7 a
T8	Gly+chl+flu+2,4-D (1080+22.5+65.6+670)	68 b	85 b	85 b	85 b	ns3740.1 b
T9	Gly+chl+flu+2,4-D (1080+22.5+65.6+670)	65 b	84 b	83 b	89 b	ns3673.2 b
T10	Gly+chl+flu+2.4-D (1080+30+87.5+670)	73 b	90 b	89 b	89 b	ns3728.1 b
T11	Gly+chl+flu+2.4-D (1080+50+50+670)	67 b	80 b	83 b	85 b	ns3648.2 b
T12	Gly+chl+2.4-D (1080+22.5+670)	43 d	74 c	79 c	88 b	ns3748.5 b
T13	Gly+chl+2,4-D+saflu (1080+25+670+50)	99 a	100 a	100 a	96 a	ns3887.8 a
T14	Gly+flu+2.4-D (1080+65.6+670)	69 b	82 b	90 b	90 b	ns3724.1 b
T15	Gly+dicl+2.4-D (1080+25.2+670)	46 d	66 d	70 d	65 e	**3546.7 c
T16	Gly+2.4-D (1080+670)	32 d	51 e	61 d	54 f	**3374.6 c
T17	Weeded control sample	100 a	100 a	100 a	100 a	4036.5 a
T18	Infested control sample	0 e	0 f	0 e	0 g	**3040.8 d
Average		58	70	73	75	3615.6
C.V. (%)		12.6	7.4	5.9	5.7	8.9

* On the right of the number: averages followed by different letters in the column differ by Scott-Knott test (p≤0.05). ** On the left of the number: significant in relation to the weeded control sample by Dunnett test (p≤0.05); ns On the left of the number: non-significant in relation to the weeded control sample by Dunnett test (p≤0.05).

On day seven DAA, hairy fleabane control was lower than 74% for all herbicides combinations, except in the weeded control sample and in the treatment were there was the association of glyphosate, chlorimuron-ethyl, 2,4-D and saflufenacil (T13), which presented over 98% of control (Table 2). Similar results were obtained in the control of glyphosate-resistant hairy fleabane in cotton-cultivated areas in the United States, where the tank mix of glyphosate with saflufenacil and glyphosate with dicamba provided over 90 and 70% control, respectively, suggesting that there is a synergic effect between molecules (Waggoner et al., 2011; Eubank et al., 2013). As for saflufenacil, the inhibition of the protox enzyme and the production of free radicals caused lipid peroxidation of the cell membranes; this is a process that occurs in a slower way compared to other contact herbicides, allowing the translocation of systemic herbicides in a more effective way, even when they are used in a mixture (Eubank et al., 2013).

On day 14 DAA, it was observed that the association of 2,4-D to glyphosate, chlorimuron-ethyl and flumioxazin increased control from 20 to 38% when compared to treatments where 2,4-D was not added (Table 2). When comparing equivalent treatments with or without the addition of 2,4-D, the control increase becomes evident; without 2,4-D, it varied from 55 to 65% and from 75 to 90% when there was 2,4-D addition (Table 2). These results support the low control levels obtained on day 14 DAA in the association of glyphosate with chlorimuron-ethyl and flumioxazin (Moreira et al., 2010). The increase in controlling resistant hairy fleabane with the association of 2,4-D is due to the synergism with glyphosate, which helps the absorption and translocation (Waggoner et al., 2011; Takano et al., 2013), contrasting the possible antagonistic effects of the mixture glyphosate with chlorimuron-ethyl and flumioxazin over morning glory, where there was control reduction up to 30% (Shaw; Arnold, 2002). These results support the importance of 2,4-D associated to glyphosate, in order to improve the control of glyphosate-resistant hairy fleabane (Werth et al., 2010; Lamego et al., 2013).

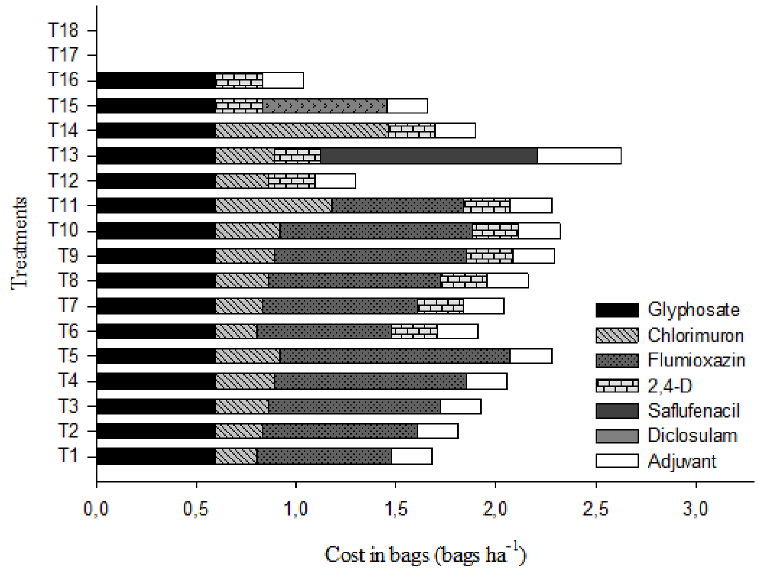
As for hairy fleabane control on day 21 and 35 DAA, the obtained results demonstrated that the use of the association of glyphosate, chlorimuron-ethyl, 2,4-D and saflufenacil (T13) provided over 96% control; this was not statistically different from the weeded control sample (Table 2). Similar results were obtained with the mixture of glyphosate with saflufenacil and glyphosate with dicamba, where there was over 98% control on resistant biotypes of *C. canadensis* in soybean (Budd et al., 2016). This association, as well as presenting a different action mechanism, may have been helped by the occurrence of molecule synergism, which improved absorption and translocation and allowed the increase in control levels (Dalazen et al., 2015b; Budd et al., 2016).

Other treatments deserving emphasis are glyphosate associated to chlorimuron-ethyl and 2,4-D (T12) and glyphosate associated with flumioxazin and 2,4-D (T14), where control was 88 and 90%, respectively. However, no control increase was observed when chlorimuron-ethyl and flumioxazin were associated to glyphosate and 2,4-D, even with increased rates (Table 2). These results do not support Dalazen et al. (2015a), who demonstrate effective control of hairy fleabane seedlings in winter cereals by the application of flumioxazin and 2,4-D. Probably, the non-improvement in controlling hairy fleabane by the application of the association of chlorimuron-ethyl and flumioxazin even with increased rates may be due to the development stage of hairy fleabane plants, since the recommendation of these herbicides is directed to young plants management.

As for soybean yield, it was observed that the application of herbicides in association provided yield profits, which varied between 11 and 28% when compared with the infested control sample (Table 2). The highest yield was observed in the weeded control sample followed by treatments were glyphosate, chlorimuron-ethyl, 2,4-D and saflufenacil (T13) and glyphosate, chlorimuron-ethyl, flumioxazin and 2,4-D (T7) were associated (Table 2). High control levels are fundamental, since the yield loss caused by the competition of resistant hairy fleabane in soybean may vary from 4 to 21 kg ha^{-1} per day, depending on the population and the development stage of culture and hairy fleabane (Silva et al., 2014).

Herbicide cost varied between 0.83 (R$ 57.00) and 2.63 (R$ 180.00) soybean bags per hectare, which represents 1.23 and 3.9% of the final yield of the weeded control sample, respectively (Table 2, Figure 3). Treatments with glyphosate, chlorimuron-ethyl and 2,4-D (T12) and glyphosate associated to 2,4-D (T16) presented the lowest costs, whereas the most expensive treatment was the association of glyphosate, chlorimuron-ethyl, 2,4-D and saflufenacil (T13) (Figure 3).

Through the yield obtained in herbicide treatments in relation to the infested control sample, it is evident that, even in treatments where the hairy fleabane control was lower, there were yield profits that varied from 5.6 to 14.1 bags ha^{-1}, and they were directly proportional to the obtained control (Figure 4).



Average herbicide (commercial product) price: glyphosate (R$ 13.50 L^{-1}); chlorimuron-ethyl (R$ 200.00 kg^{-1}); flumioxazin (R$ 450.00 kg^{-1}); 2,4-D (R$ 16.70 L^{-1}); saflufenacil (R$ 920.00 kg^{-1}); diclosulam (R$ 1420.00 kg^{-1}); Adjuvants: DASH® Basf – R$ 20.00 L^{-1}; Nimbus® Syngenta – R$ 18.00 L^{-1}; Assist® Basf – R$ 17.00 L^{-1}; Soybean R$ 68.50 (bag 60 kg^{-1}).

Figure 3. Cost of the herbicides (bags ha^{-1}) used to manage glyphosate-resistant *Conyza* spp. in RR® soybean pre-emergence. Passo Fundo (RS) 2014/2015.

For the economic return (ER) of treatments in relation to the infested control sample, it was possible to observe a variation from 4.7 to 11.5 bags ha^{-1} among the studied treatments; this was below the ER obtained for the weeded control sample, which was 16.6 bags ha^{-1} (Figure 4). However, it is important to highlight that labor costs were not considered for the weeded control sample. The highest ER occurred in the association of glyphosate, chlorimuron-ethyl, flumioxazin, 2,4-D (T7), glyphosate, chlorimuron-ethyl, 2,4-D (T12) and glyphosate, chlorimuron-ethyl, 2,4-D and saflufenacil (T13), being directly proportional to control (Table 2; Figure 4).

When evaluating the relative economic return (RER) of the investment to control hairy fleabane, the obtained values varied from 4.4 (T11) to 9.2 (T12) bags ha^{-1}, with an emphasis on the treatment glyphosate, chlorimuron-ethyl and 2,4-D (T12) (Figure 4), that is, for each soybean bag invested in fleabane control, there was a return of 9.1 bags in the final yield. However, for the treatments T7, T12 and T13 the RER was 6.2, 9.1 and 5.4 soybean bags ha^{-1} (Figure 4). Thus, the studied herbicide associations for the chemical control of hairy fleabane are viable from a technical and economic point of view, especially in scenarios where there is investment risk and with relatively small profit margins (Longenecker et al., 2011); this may be considered an important parameter for analyses and as a criterion when making decisions.

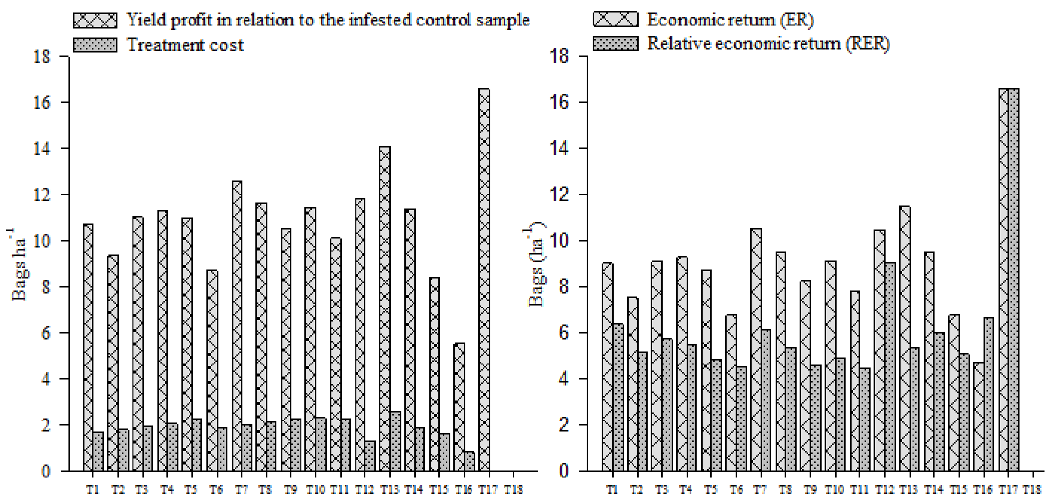


Figure 4. Soybean yield profit of the treatments in relation to the infested control sample (bags ha^{-1}), treatment cost (bags ha^{-1}), economic return (ER) and relative economic return (RER) of the used treatments in the management of glyphosate-resistant *Conyza* spp. in RR® soybean pre-emergence. Passo Fundo (RS), 2014/2015.

Conclusions

The best technical effectiveness was observed for the association of glyphosate + chlorimuron-ethyl + flumioxazin + 2,4-D (T7) and glyphosate + chlorimuron-ethyl + 2,4-D + saflufenacil (T13).

The best economic return was obtained for the treatments glyphosate + chlorimuron-ethyl + flumioxazin + 2,4-D (T7), glyphosate + chlorimuron-ethyl + 2,4-D (T12) and glyphosate + chlorimuron-ethyl + 2,4-D + saflufenacil (T13).

The association and increase in chlorimuron-ethyl and flumioxazin rates did not improve the control of hairy fleabane in the studied treatments.

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