Herbicides applied in pre and post-emergence to control *Chamaesyce hirta*[1]

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ABSTRACT

In view of the increase in the infested areas and the difficulty in controlling *Chamaesyce hirta* (L.) Millsp (garden spurge) there is growing interest in identifying herbicides that can be applied in pre and post-emergence, helping to reduce infestation and to provide species control. The objective of this work was to evaluate efficient alternatives of herbicides applied in pre and post emergence aiming at the control of *Chamaesyce hirta*. Three experiments were carried out in a greenhouse in a completely randomized design with four replications. The first with the application of herbicides in pre-emergence, the second with the application of herbicides in post-emergence when the plants of *C. hirta* had two to four true leaves fully expanded, and the third experiment, also with the post-emergence application at the flowering and branching stage of the plants. For herbicides applied in pre-emergence, at 28 days after application (DAA), all herbicides evaluated were considered effective for the control of *Chamaesyce hirta*, showing results above 90%. Several herbicides were efficient in controlling the species with two to four leaves, however, in the flowering stage, there is greater difficulty in control, showing the importance of the plant stage at the time of application.

Keywords: chemical control; *Euphorbia hirta*; garden spurge; infestation; weeds.

INTRODUCTION

Tolerance is the innate ability of weed species to survive and reproduce after the application of the herbicide, that is, tolerant plants naturally have the ability to survive the application of the herbicide, which differentiates them from the species described as resistant (Christoffoleti *et al*., 2016). *Chamaesyce hirta* is considered a glyphosate-tolerant species and so far there are no reports of resistance to any mechanism of action (Heap, 2020).

Chamaesyce hirta (L.) Millsp (garden spurge) is an annual species of short cycle, of the Euphorbiaceae family, with small inflorescences and great seed production potential (Snell & Burch, 1975; Pinto *et al*., 2014). The dispersion of the species has raised concerns, mainly because this plant is considered difficult to control (Santos *et al*., 2016). The limited number of non-chemical control alternatives is another concern in relation to the species.

Among the control methods, chemical management, in addition to being the most used, is considered more practical, effective and economical (Yadav *et al*., 2017), however, so far, there is a limited number of studies evaluating the effectiveness of herbicide treatments to control *C. hirta* in pre- and post-emergence. In the case of herbicides applied in post-emergence, there are reports of adequate control of *C. hirta* with the association of chlorimuron-ethyl (10 g ha^{-1}) to glyphosate (1440 g ha^{-1}) (Procópio *et al*., 2007), as well as by using glyphosate (960 g ha^{-1}) in plants with an average of three leaves (Petter *et al*., 2007).

The application of herbicides in pre-emergence is an important tool in weed management (Hasty *et al*., 2004), both by promoting initial competitive advantage for the crop, and by allowing the use of mechanisms of action normally different from those used in post-emergence, which is one of the main reasons to prevent the selection of resistant populations. The application of herbicides in pre-emergence can help, for example, in reducing weed infestation that is difficult to control or with a history of

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resistance to glyphosate (Mueller *et al*., 2014). In addition, when compared to manual and mechanical control methods, it presents advantages such as high operational performance, control efficiency and a longer residual period (Niz *et al*., 2018).

Several studies have reported the presence of *Chamaesyce hirta* in the weed community in different locations (Singh *et al*., 2015; Amim *et al*., 2016; Santos *et al*., 2016; Forte *et al*., 2017; Kaur *et al*., 2018). *Chamaesyce hirta* was among the most abundant species in number of individuals and dry biomass of shoots in an experiment carried out in the southwestern Goiás region (Santos *et al*., 2018a). In another study, carried out in the state of Roraima, *Chamaesyce hirta* was considered one of the most important species of the studied area (Gonzaga *et al*., 2018).

In view of the reports of an increase in *C. hirta* infestation, the selection of herbicides that have potential for its control is essential to support management systems for this species. The objective of this work was to evaluate efficient alternatives of herbicides applied in pre-and post-emergence aiming at the control of *Chamaesyce hirta*.

MATERIAL AND METHODS

Three experiments were carried out in a greenhouse, between the months of February and March 2018, in a completely randomized design with four replications. The first experiment was carried out with the application of herbicides in pre-emergence. The second with the application of herbicides in post-emergence when the plants of *C. hirta* had two to four true leaves fully expanded, and the third experiment, also with the application in post-emergence in the flowering and branching stage of the plants. The seeds were purchased for the three experiments and have the same biotype. Herbicides were chosen from recommendations for weeds from the same family in different crops.

Pots with a capacity of 5 dm^3 were filled with soil with a clay-loam texture, which had the following characteristics: pH in $CaCl_2$ = 5.3; 7 g dm^{-3} of C; 69.6% sand; 6.9% silt and 23.5% clay.

Experiment 1 - Herbicides applied in pre-emergence

In each pot 50 seeds of *Chamaesyce hirta* were sown on the soil surface and then irrigation was carried out to enable the application of treatments with moist soil.

For herbicides applied in pre-emergence, 23 treatments were evaluated, whose doses are in parentheses: pendimethalin (1000 g ha^{-1}), trifluralin (1350 g ha^{-1}), S-metolachlor (1440 g ha^{-1}), pyroxasulfone (100 g ha^{-1}), indaziflam (75 g ha^{-1}), diclosulam (25.2 g ha^{-1}), chlorimuron-ethyl (15 g ha^{-1}), imazapic (105 g ha^{-1}), trifloxysulfuron-sodium (75 g ha^{-1}), [imazapic + imazapyr] ([52.5 + 17.5] g ha^{-1}), imazethapyr (106 g ha^{-1}), imazaquin (150 g ha^{-1}) , [flumioxazin + imazethapyr] ([50 + 106] g ha^{-1}), sulfentrazone (400 g ha^{-1}), flumioxazin (50 g ha^{-1}), fomesafen (250 g ha^{-1}), isoxaflutole (60 g ha^{-1}), clomazone (1000 g ha^{-1}), atrazine (2500 g ha^{-1}) metribuzin (480 g ha^{-1}), ametryn (1500 g ha^{-1}), amicarbazone (280 g ha^{-1}) and control without application.

Experiments 2 and 3 - Herbicides applied in post-emergence

Sowing was carried out on the soil surface and thinning in the establishment of the species, with four plants remaining for the experiment 2 and two plants for the experiment 3 in each pot. All pots were irrigated daily, for the development of the species.

For the experiment with plants in the stage of two to four leaves and for the experiment with flowering plants, 29 treatments were evaluated with the following doses of each herbicide: fomesafen (202.5 g ha^{-1}), lactofen (150 g ha^{-1}), saflufenacil (24.5 g ha^{-1}), flumioxazin (30 g ha^{-1}), flumiclorac-pentyl (40 g ha^{-1}), carfentrazone-ethyl (10 g ha^{-1}), bentazon (720 g ha^{-1}), atrazine (1500 g ha^{-1}), imazethapyr (100 g ha^{-1}), cloransulam-methyl (30 g ha^{-1}), trifloxysulfuron-sodium (7.5 g ha^{-1}), nicosulfuron (50 g ha^{-1}), chlorimuron-ethyl (10 g ha^{-1}), [imazapic + imazapyr] ([52.5 + 17.5] g ha^{-1}), mesotrione (120 g ha^{-1}), tembotrione (75 , 6 g ha^{-1}), 2,4-D (670 g ha^{-1}), dicamba (470 g ha^{-1}), diquat (200 g ha^{-1}), paraquat (200 g ha^{-1}), paraquat (400 g ha^{-1}), paraquat + 2,4-D (200 + 670 g ha^{-1}), paraquat + 2,4-D (400 + 670 g ha^{-1}), glufosinate-ammonium (400 g ha^{-1}), glufosinate-ammonium + 2,4-D (400 + 670 g ha^{-1}), glyphosate (1080 g ha^{-1}), glyphosate + 2,4-D (1080 + 670 g ha^{-1}), glyphosate + 2,4-D (1080 + 335 g ha^{-1}) and control without application.

The application of treatments in all experiments was carried out using a backpack sprayer of constant pressure based on CO_2, equipped with bar with four flat fan XR-110.02 tips (207 kPa) spaced 0.50 m from each other and with an application height of 0.50 m above the edge of the pots. These conditions resulted in an application rate of 200 L ha^{-1}. At the time of application, the soil of the pots was moist; the temperature at 26ºC, the relative humidity of the air was 62%, winds of 5 km h^{-1} and a cloudless sky. All herbicide treatments were applied on the same day.

The control of *Chamaesyce hirta* was evaluated at 7, 14, 21 and 28 days after application (DAA) in the experiment with herbicides applied in pre-emergence. For experiments with herbicides applied in post-emergence, the evaluation took place at 14 and 28 DAA. A visual scale from 0 to 100% was used, where 0% corresponds to no control and 100% the death of all plants compared to the control (SBCPD, 1995).

Statistical analyses were performed using the Sisvar software (Ferreira, 2011). Data related to normality were

analyzed using the Shapiro-Wilk test ($p < 0.05$) and for homogeneity of variances using the Levene test ($p < 0.05$). The assumptions of variance were adequately met. Then, analysis of variance was performed using the F test and the means were compared using the Scott-Knott cluster test ($p < 0.05$).

RESULTS AND DISCUSSION

Experiment 1 - Herbicides applied in pre-emergence

Two groups of treatments were identified. In the first, the herbicides that promoted control above 75% since the first evaluation (pendimethalin, S-metolachlor, pyroxasulfone, indaziflam, diclosulam, [flumioxazin + imazethapyr], sulfentrazone, flumioxazin, fomesafen, clomazone, atrazine, metribuzin and metribuzin stand out ametryn). In a second group, the initial control (7 DAA) is inferior to the previous group of herbicides, but it is improved along the evaluations: trifluralin, chlorimuron-ethyl, imazapic, trifloxysulfuron-sodium, [imazapic + imazapyr], imazethapyr, imazaquin, isoxaflutole and amicarbazone (Table 1).

For indaziflam, [flumioxazin + imazethapyr], flumioxazin and fomesafen no seedlings emerged during the evaluation period, showing maximum control of the species. When evaluating the effect of indaziflam on the seedbank of sugarcane crop soil during four consecutive harvests, Amim *et al*. (2016) observed that this herbicide at 75 g ha^{-1} showed 100% control of *C. hirta* in the layers 0 to 10 and 10 to 20 cm of soil. In a study conducted by Wehtje *et al*. (2015) with different formulations and doses of flumioxazin applied in pre-emergence, there was an efficiency greater than 85% in the control of *Chamaesyce maculata*, which belongs to the same family and genus of *Chamaesyce hirta*.

Other studies in the literature demonstrate the efficiency of herbicides in controlling *Chamaesyce hirta*, such as mixtures of trifluralin + diuron (1335 + 800 g ha^{-1}), [clomazone + carfentrazone-ethyl] + prometryn ([600 + 15] + 1000 g ha^{-1}), prometryn + S-metolachlor (1000 + 960 g ha^{-1}), [clomazone + carfentrazone-ethyl] + diuron ([600 + 15] + 800 g ha^{-1}), and prometryn + trifluralin (1000 + 1335 g ha^{-1}) applied in pre-emergence, which showed values higher than 75% in the evaluations performed at 20 and 35 days after application (Santos *et al*., 2018b). In this study, the isolated use of the herbicides trifluralin, S-metolachlor and clomazone in a greenhouse demonstrated effective control of *C. hirta*, eliminating the need for associations with other herbicides.

The application of dimethenamid-P + pendimethalin in pre-emergence using two formulations of the herbicide and different irrigation volumes resulted in efficient control of *C. hirta* in all combinations (Saha *et al*., 2019). In another study, the application of pendimethalin in pre-emergence followed by the application of bispyribac-sodium in post-emergence also provided efficient control, significantly decreasing the density of plants of the species (Singh *et al*., 2015). Although in this study pendimethalin was applied with no further addition of another herbicide, the results are similar, providing maximum control of the species in the last two evaluations.

In general, all the herbicides used were considered effective for the control of *Chamaesyce hirta* in the evaluation performed at 28 DAA, providing above 90% control. Other herbicides can also be used to control the species, such as diuron + hexazinone + sulfometuron-methyl and tebuthiuron which, when applied on sugarcane stalk, in different periods without rain after application (0, 15, 30 and 45 days) provided 100% control of *C. hirta* (Ferreira *et al*., 2016).

There are several efficient herbicide options that can be used in pre-emergence in areas infested with *Chamaesyce hirta*, which may be linked to the fact that the seeds are very small and emerge from relatively small depths. Such options can be used in different crops to reduce the number of plants that emerge and, consequently, the levels of infestation remaining during their cycle.

Even though some herbicides have a slower action on the first days after application, all herbicides applied in pre-emergence in this study were efficient alternatives for the control of *Chamaesyce hirta*.

Experiments 2 and 3 - Herbicides applied in post-emergence

Regarding the control of *Chamaesyce hirta (L.)* with two to four leaves (Table 2), in the first evaluation (14 DAA), the herbicides saflufenacil, flumioxazin, atrazine, trifloxysulfuron- sodium, nicosulfuron, diquat, paraquat (both doses), paraquat + 2,4-D (both doses), glufosinate-ammonium, glufosinate-ammonium + 2,4-D, glyphosate and glyphosate + 2,4-D (higher dose) provided 100% control of the species. The herbicides carfentrazone-ethyl and bentazon were less efficient, with the latter showing equivalent results to the control without application.

The herbicides lactofen, cloransulam-methyl and mesotrione, although not reaching 100% of control, presented satisfactory levels, however, in the same treatments there is a decrease in control at 28 DAA. In addition, the herbicides fomesafen and dicamba start from 72.5 and 65% in the initial evaluation to 25 and 10% in the final evaluation, respectively. These results demonstrate the potential of recovery and development of the plant along the the evaluation period, which makes the control of the species even more difficult.

The association of paraquat, glufosinate-ammonium and glyphosate with 2,4-D provided levels of control similar to those observed for the application of these herbicides alone, not justifying mixtures with 2,4-D, since there is no

increase in efficacy. Similarly, the application of paraquat alone, in both doses, was similar, indicating that in this case there is no need to increase the dose for the control of *Chamaesyce hirta*.

For the control of flowering plants of *Chamaesyce hirta* (L.) (Table 2), there is an evident decrease in control levels when compared to the earlier stage development. Herbicide treatments such as saflufenacil, flumioxazin, nicosulfuron, diquat, paraquat (both doses) and glufosinate-ammonium, which provided maximum control at 28 DAA applied at the stage of two to four leaves, demonstrated control lower or equal to 55% when the application was carried out at the flowering stage, showing the importance of the plant stage at the time of herbicide application.

The reduction in viable control options after weed development can result in significant damage to the production of the crop of interest and hinder the adoption of management systems for other weeds present in the area. These results are evident when observing the control data with the application of fomesafen, lactofen, saflufenacil, flumiclorac-penthyl, carfentrazone-ethyl, bentazon, cloransulan-ethyl, clorimuron-ethyl, mesotrione, tembotrione, 2,4-D, dicamba and glufosinate-ammonium at 28 DAA, which provided control similar to the control without application.

Control results of *Chamaesyce hirta* with chlorimuron-ethyl were observed by Procópio *et al*. (2007) only when this herbicide was used at a dose of 10 g ha^{-1} in association with glyphosate (1440 g ha^{-1}), presenting 95% control of plants with four to eight leaves. The association of these herbicides may have caused synergism, differing from the results obtained in this work for chlorimuron-ethyl alone.

Glyphosate was the only herbicide that showed 100% control for flowering plants in the evaluation at 28 DAA, however, the herbicides atrazine, trifloxysulfuron-sodium, paraquat + 2,4-D, glufosinate-ammonium + 2,4-D and glyphosate + 2,4-D (both doses) showed control ranging from 93.2 to 98.2%, which characterizes them as interesting alternatives for the control of *Chamaesyce hirta*. In a study with the isolated application of glyphosate at doses of 480, 960 and 1440 g ha^{-1} at the stage of four and eight leaves, the authors obtained results different from those found in this study and

Table 1: *Chamaesyce hirta* control percentages at 7, 14, 21 and 28 days after application (DAA) of pre-emergence herbicide treatments

Herbicides (g ha^{-1})	***Chamaesyce hirta* control %**			
	7 DAA	**14 DAA**	**21 DAA**	**28 DAA**
pendimethalin (1000)	76.2 b	94.5 b	100.0 a	100.0 a
trifluralin (1350)	0.0 e	45.0 g	90.0 d	90.0 e
S-metolachlor (1440)	86.2 b	100.0 a	100.0 a	100.0 a
pyroxasulfone (100)	97.5 a	100.0 a	100.0 a	100.0 a
indaziflam (75)	100.0 a	100.0 a	100.0 a	100.0 a
diclosulam (25,2)	77.5 b	97.5 b	100.0 a	100.0 a
chlorimuron-ethyl (15)	40.0 c	85.2 e	97.2 b	97.2 b
imazapic (105)	32.5 d	89.5 d	98.0 b	98.0 b
trifloxysulfuron-sodium (7,5)	30.0 d	92.5 c	98.0 b	98.0 b
[imazapic + imazapyr] [52,5+17,5]	30.0 d	90.0 d	98.0 b	98.0 b
imazethapyr (106)	30.0 d	88.7 d	98.0 b	98.0 b
imazaquin (150)	30.0 d	81.5 f	95.0 c	95.7 c
[flumioxazin + imazethapyr] [50+106]	100.0 a	100.0 a	100.0 a	100.0 a
sulfentrazone (400)	99.5 a	99.5 a	100.0 a	100.0 a
flumioxazin (50)	100.0 a	100.0 a	100.0 a	100.0 a
fomesafen (250)	100.0 a	100.0 a	100.0 a	100.0 a
isoxaflutole (60)	52.5 c	96.2 b	100.0 a	100.0 a
clomazone (1000)	85.0 b	97.5 b	100.0 a	100.0 a
atrazine (2500)	96.2 a	96.2 b	98.7 b	98.7 b
metribuzin (480)	81.2 b	92.5 c	97.0 b	97.0 b
ametryn (1500)	87.5 b	94.5 b	95.0 c	93.7 d
amicarbazone (280)	45.0 c	99.5 a	99.5 a	100.0 a
Untreated check	0.0 e	0.0 h	0.0 e	0.0 f
F	28.2*	369.4*	2532.2*	1707.8*
CV (%)	19.9	2.6	0.8	1.0

* Means followed by the same letters in the columns do not differ from each other by the Scott-Knott test ($p \leq 0.05$).

Table 2: Percentages of *Chamaesyce hirta* control in the stage of two to four leaves and in flowering, at 14 and 28 days after application (DAA) of post-emergence herbicide treatments

Herbicides (g ha^{-1})	*Chamaesyce hirta* control %			
	Two to four leaves		Flowering	
	14 DAA	28 DAA	14 DAA	28 DAA
fomesafen (202,5)[1/]	72.5 d	25.0 e	5.0 g	1.2 e
lactofen (150)	90.0 b	43.7 d	13.7 f	2.5 e
saflufenacil (24,5)[2/]	100.0 a	100.0 a	20.0 f	2.5 e
flumioxazin (30)[2/]	100.0 a	100.0 a	87.5 a	48.7 c
flumiclorac-penthyl (40)[3/]	74.5 d	27.5 e	6.2 g	1.2 e
carfentrazone-ethyl (10)[2/]	20.0 f	10.0 f	0.0 g	0.0 e
bentazon (720)[2/]	5.0 g	5.0 f	7.5 g	0.0 e
atrazine (1500)	100.0 a	100.0 a	94.5 a	96.2 a
imazethapyr (100)	91.2 b	95.0 a	0.0 g	22.5 d
cloransulam-methyl (30)[1/]	82.5 c	65.0 c	0.0 g	0.0 e
trifloxysulfuron-sodium (7,5)[1/]	100.0 a	100.0 a	95.7 a	95.0 a
nicosulfuron (50)	100.0 a	100.0 a	20.0 f	55.0 c
chlorimuron-ethyl (10)[2/]	60.0 e	79.5 b	5.0 g	0.0 e
[imazapic + imazapyr] [52,5 +17,5][4/]	98.7 a	100.0 a	30.0 e	76.2 b
mesotrione (120)[2/]	85.0 b	62.0 c	1.2 g	0.0 e
tembotrione (75,6)[5/]	62.5 e	30.0 e	0.0 g	0.0 e
2,4-d (670)	65.0 e	16.2 f	10.0 g	3.7 e
dicamba (470)	65.0 e	10.0 f	8.7 g	2.5 e
diquat (200)[6/]	100.0 a	100.0 a	42.5 d	35.0 d
paraquat (200)[6/]	100.0 a	100.0 a	72.0 c	25.0 d
paraquat (400)[6/]	100.0 a	100.0 a	93.2 a	50.0 c
paraquat + 2,4-d (200 + 670)[6/]	100.0 a	100.0 a	84.0 b	62.5 c
paraquat + 2,4-d (200 + 670)[6/]	100.0 a	100.0 a	95.7 a	98.2 a
glufosinate-ammonium (400)[3/]	100.0 a	100.0 a	45.0 d	10.0 e
glufosinate-ammonium + 2,4-d (400+670)	100.0 a	100.0 a	95.7 a	97.5 a
glyphosate (1080)	100.0 a	100.0 a	96.5 a	100.0 a
glyphosate + 2,4-d (1080 + 670)	98.7 a	100.0 a	92.0 a	97.0 a
glyphosate + 2,4-d (1080 + 335)	100.0 a	100.0 a	88.2 a	93.2 a
Untreated check	0.0 g	0.0 f	0.0 g	0.0 e
F	117.8*	99.8*	86.2*	60.5*
CV (%)	17.9	21.8	7.6	13.7

* Means followed by the same letters in the columns do not differ from each other by the Scott-Knott test ($p \leq 0.05$). [1/] Added Agral (0,2% v v^{-1}), [2/] Added Assist (0,5% v v^{-1}), [3/] Added Assist (0,2% v v^{-1}), [4/] Added Agral (0,15% v v^{-1}), [5/] Added Áureo (0,25% v v^{-1}), [6/] Added Agral (0,1% v v^{-1}).

concluded that the increase in doses resulted in an increase in control, however, not reaching satisfactory levels (Procópio *et al*., 2007).

Unlike what happened for the two to four-leaf stage, the association of paraquat and glufosinate-ammonium with 2,4-D applied at the flowering stage, increasead control when compared to the isolated application. In the case of glyphosate, the application of the herbicide alone is sufficient to achieve efficient control. Although the association of glyphosate with 2,4-D provides the same level of control as the isolated application, this management practice may be recommended in cases where there is a need to accelerate and expand the spectrum of weed control, especially for those that are difficult to control (Takano *et al*., 2013).

CONCLUSIONS

All herbicides evaluated provided effective for the control of *Chamaesyce hirta* in pre-emergence at 28 days after application, showing results above 90%.

There are options for the control of *Chamaesyce hirta* in post-emergence, such as the herbicides saflufenacil, flumioxazin, atrazine, imazethapyr, trifloxysulfuron-sodium, nicosulfuron, [imazapic + imazapyr], diquat, paraquat, glufosinate-ammonium, and the associations of glufosinate-ammonium + 2,4-D, paraquat + 2,4-D and glyphosate + 2,4-D that provided control greater than 95% when applied to plants at the stage of two to four leaves.

The best alternatives for the control of *Chamaesyce hirta* at the flowering stage were atrazine, trifloxysulfuron-

penthyl, paraquat + 2,4-D, glufosinate-ammonium + 2,4-D, glyphosate and the two doses of the combination of glyphosate + 2,4-D.

Even so, the stage of *Chamaesyce hirta* plants at the timing of application is essential to obtain success in controlling the species.

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