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Research Article

Management and development of fleabane plants in central Brazil

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The authors declare that there is no conflict of interest regarding the publication of this manuscript.

Highlights

- Chemical control associated with biological characteristics of fleabane plants in the Cerrado biome.
- Fleabane emergence is most pronounced in February and March in the Cerrado biome.
- Saflufenacil and glufosinate-ammonium were the most efficient and fastest for the control of fleabane.

Abstract

Background: Fleabane plants (*Conyza* spp.) resistant to glyphosate herbicide are found infesting areas in the Central-West and Southeast regions of Brazil, but its management is not a concerning problem for summer crops in these regions as in the South region of Brazil.
Objective: To evaluate the management of adult fleabane plants at the summer soybean crop and off-season (autumn-winter), monitoring new emergences to assess the dynamics of plants from November 2018 to March 2020, and the residual effect of herbicides applied at the end of the rainy season in the Cerrado biome, in Brasília, DF, Brazil.
Methods: Four field experiments were developed from November 06, 2018 to April 02, 2020; all under randomized block design, with four replications, in factorial or split-plot arrangement, with visual weed control evaluations (0% to 100%) and seedling counting.
Results: The highest fleabane infestations in soybean crops were found before sowing, and were partially or fully controlled by pre-sowing chemical/management treatments, which did not interfere with the soybean seed yield. The fleabane biological cycle ended in November-December (1st year), and December-January (2nd year).
Conclusions: The most significant fleabane emergence in the areas was found in February and March. The treatments with saflufenacil and glufosinate-ammonium, followed by 2,4-D, were the most efficient and fastest control of adult fleabane plants.

1 Introduction

Three fleabane species (*Conyza* spp.) have been found in Brazil, specifically in the state of Paraná, which are *Conyza bonariensis*, *Conyza sumatrensis*, and *Conyza canadensis;* they are commonly known as buva in Brazil. However, fleabane plants are distributed all over Brazil. *C. canadensis* is an annual species native to North America; *C. bonariensis* is an annual or biannual species native to South America (Ottavini et al., 2019; Wu et al., 2007); and *C. sumatrensis* is an annual species native to South America (Anastasiu and Memedemin, 2012; Hao et al., 2009). The reproduction of these three species is through seeds, which are produced in high quantity and easily disseminated by wind.

Fleabane seed germination is significantly reduced as the soil depth is increased, and is favored by sandy soils (Vidal et al., 2007; Wu et al., 2007). The seeds are photoblastic positive, have longevity of at least 3 years in the soil, optimal germination temperature of 20 ºC, and germinate between 10 and 25 ºC (Vidal et al., 2007; Wu et al., 2007; Zinzolker et al., 1985). The need for light to start germination can explain the higher infestation of these species in soils under more conservationist agricultural systems, with low soil disturbance, as the no-till system (Bajwa et al., 2016; Vidal et al., 2007; Wu et al., 2007). In addition to compete for water, light, and nutrients, fleabane plants can chemically suppress other plants and be host alternatives for pests, causing yield and quality losses in several crops (Andrade et al., 2012; Bajwa et al., 2016; Dalazen et al., 2017; Shaukat et al., 2003).

The main method used to control fleabane in agricultural areas is chemical. However, the frequent use of herbicides with the same mechanism of action select resistant biotypes. The first case of resistance of fleabane to herbicides in Brazil was reported in 2005 for *C. bonariensis* to glyphosate, in the states of Rio Grande do Sul and São Paulo. In 2006 a case of resistance was found for *C. canadensis* in the state of São Paulo; and in 2010 for *C. sumatrensis* in the state of Paraná (Heap, 2020). Resistance is an inherent and inheritable capacity of some biotypes within a population to survive and reproduce after exposed to herbicide rates that are lethal to the normal individuals (susceptible) of the species (Christoffoleti and López-Ovejero, 2008).

Increasing infestations of resistant weed biotypes in agricultural production systems may increase production costs due to the need for adoption of other weed management strategies and may decrease crop yield due to competition with non-controlled weeds. The control of resistant weeds is difficult and requires strategies for the choice of herbicides and medium- and long-term managements of the area. Thus, information on fleabane emergence dynamics in agricultural areas assist in defining the adequate time for application of herbicides and establishing the herbicide residual effects in the soil for the control of weeds that will emerge (Gianelli et al., 2017). This is important for the Cerrado biome, which presents a well-defined dry season - from April/May to September/October) - that is the main limiting factor for the development and emergence of new plants (Silva et al., 2008).

Fleabane became a problem in the South region of Brazil, with cases of resistance to several herbicides (glyphosate, chlorimuron, paraquat, and saflufenacil), including multiple resistance (glyphosate-chlorimuron, glyphosate-chlorimuron-paraquat, diuron-paraquat-saflufenacil-glyphosate-2,4-D) (Heap, 2020). However, although resistant fleabane plants to glyphosate herbicide are found in high infestation in the Central-West and Southeast regions of Brazil, its management is not as worrying for summer crops as in the South. Fleabane emergence in these regions is reduced in November and December, resulting in no significant densities. Most plants emerge in February and March and reach senescence stage in November, since fleabane plants have annual cycle in the Cerrado biome when not controlled. Therefore, information on plant dynamics, including emergence, growth, and senescence over the year is important to establish more consistent management strategies for these regions.

The objective of this work was to evaluate the management of adult fleabane plants at the summer soybean crop and off-season (autumn-winter), monitoring new emergences to assess the dynamics of plants from November 2018 to March 2020, and the residual effect of herbicides applied at the end of the rainy season in the Cerrado biome, in Brasília, DF, Brazil.

2 Material and Methods

Four field experiments were conducted in Brasília, DF, Brazil, from November, 06, 2018 to April 02, 2020. Experiment 1 (November 06, 2018 to January 31, 2019) and 4 (November 23, 2019 to April 02, 2020) evaluated the control of adult fleabane plants at burndown, before the soybean sowing, and the dynamics of new emergence events of these species in soybean crops. Experiment 2 (March 12, 2019 to April 25, 2019) evaluated the control of adult fleabane plants at the beginning of flowering, from of first emergence event of the year, in a fallow area. Experiment 3 (April 08, 2019 to December 07, 2019) evaluated fleabane plants at full reproductive stage (flower, fruit, and seed) at burndown for controlling plants and residual effect of the herbicides in the soil on the inhibition of fleabane emergence in the autumn-winter season, in fallow area.

The latitude, longitude and altitude of the areas were 15º35'48.8"S, 47º43'04.7"W, and 997 m (Experiment 1); 15º35'58"S, 47º42'59"W and 1001 m (Experiment 2); 15º36'01"S, 47º43'00"W, and 1004 m (Experiment 3); 15º35'51.1"S, 47º43'05.5"W, and 973 m (Experiment 4). The climate of the region is Aw, tropical wet with dry winter, according to the Köeppen classification (Cardoso et al., 2014). The soil of the areas is representative of region, classified as Typic Hapludox of clayey texture.

The total rainfall depths (15-day period) and mean, maximum, and minimum monthly temperatures from October 01, 2018 to March 31, 2020, recorded by a climatic station at approximately 1.0 km of the areas, are presented in Figure 1.

In Experiments 1 and 4, soybean seeds of the cultivar Conkesta E3, which is tolerant to the herbicides 2,4-D, glyphosate, and glufosinate-ammonium, and has the Bt protein, were sowed under no-till system, at 7 and 10 days after the first herbicide application to the plots, respectively. Cultural practices were carried out for a better establishment and development of the crop, including soil fertilization, seed inoculation, and plant health protection. In Experiment 1, soybean seeds were sowed in a fallow area (without autumn-winter crop), and in Experiment 4, soybean crops succeeded winter maize under glyphosate application (1.08 kg a.e. ha^{-1}) for weed management.

Experiment 1 was conducted in a randomized block design with four replications, using a 4×2+2 factorial arrangement consisted of five herbicidal treatments, with and without glufosinate-ammonium applied after 7 days, a treatment with glyphosate only, and a control without herbicide application.

The herbicides evaluated were: 2,4-D at 1.209 kg ha^{-1} + glyphosate at 1.92 kg a.e. ha^{-1}; carfentrazone-ethyl at 40.0 g ha^{-1} + glyphosate at 1.92 kg a.e. ha^{-1} + mineral oil at 0.5%; flumioxazin at 50.0 g ha^{-1} + glyphosate at 1.92 kg a.e. ha^{-1} + mineral oil at 0.5%; and saflufenacil at 98.0 g ha^{-1} + glyphosate at 1.92 kg a.e. ha^{-1} + mineral oil at 0.5%, with and without additional application of glufosinate-ammonium at 400 g ha^{-1} + 0.2% vegetal oil) after 7 days; and glyphosate applied single at 1.92 kg a.e. ha^{-1}. The additional applications were carried out done at 4.5 hours before the soybean sowing.

Herbicides were applied at post-emergence of soybean at 22 days after the sowing. The herbicides 2,4-D at 1.14 kg ha^{-1} + glyphosate at 0.82 kg a.e. ha^{-1} were used for the treatments 1 to 4; and glyphosate at 1.92 kg a.e. ha^{-1} was used for the additional treatment, 3.84 kg a.e. ha^{-1} divided into pre-sowing burndown and post-emergence of soybean.

Experiment 2 was conducted in a randomized block design, in a 6×2+1 split-plot arrangement, with 4 replications, with six herbicidal treatments, with and without additional application, and a control treatment without herbicide application. The herbicides evaluated were 2,4-D at 1.209 kg ha^{-1} + glyphosate at 1.2 kg a.e. ha^{-1}; carfentrazone-ethyl at 40.0 g ha^{-1} + glyphosate at 1.2 kg a.e. ha^{-1} + mineral oil at 0.5%; flumioxazin at 50.0 g ha^{-1} + glyphosate at 1.2 kg a.e. ha^{-1} + mineral oil at 0.5%; saflufenacil at 98.0 g ha^{-1} + glyphosate at 1.2 kg a.e. ha^{-1} + mineral oil at 0.5%; glufosinate-ammonium at 400 g ha^{-1} + 0.2% vegetal oil; and glyphosate applied single at 1.92 kg a.e. ha^{-1}, with and without additional application of glufosinate-ammonium at 400 g ha^{-1} + 0.2% vegetal oil for treatments 1 to 5, or glyphosate at 1.92 kg a.e. ha^{-1} for treatment 6, after 7 days.

Experiment 3 was conducted in a randomized block design with 4 replications, using a 7 x 2 split-plot arrangement consisted of six residual herbicides and a control without application, with and without previous desiccation in the area with glufosinate-ammonium at 500.0 g ha^{-1} + 0.2% vegetal oil. The purpose of this desiccation was to kill adult fleabane plants and other weed species to prepare the areas

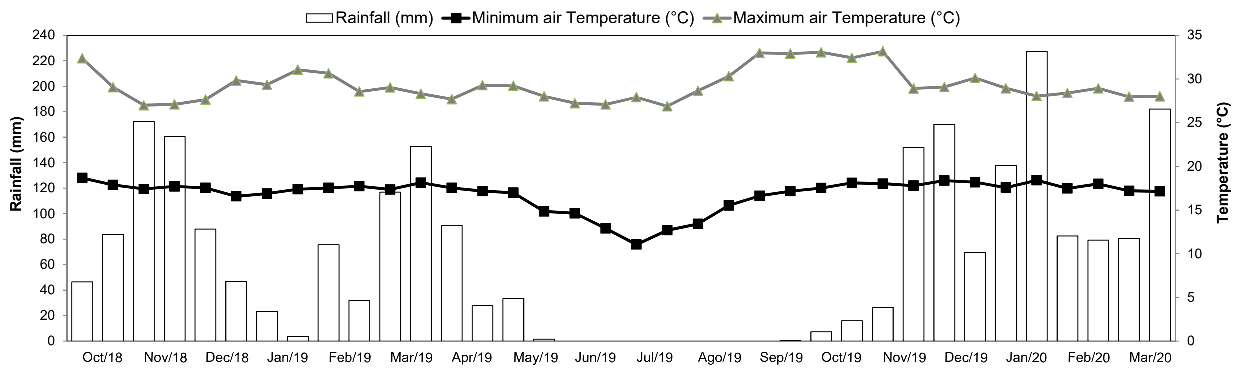

Figure 1 - Total rainfall depth (15-day period) and mean monthly minimum and maximum air temperatures recorded by the climatological station of the Embrapa Cerrados, from October 01, 2018 to March 31, 2020.

for the residual herbicides, applied on the plant residues. In the areas without previous burndown herbicide application, herbicides were applied on the soil green cover, which was above 30%. In the control, the previous burndown was important to eliminate weeds and allow the emergence of new fleabane plants in the area, which was difficult due to the great plant cover resulted from the lack of previous burndown.

The residual herbicides were applied at eight days after the burndown herbicide application using atrazine at 1.5 kg ha^{-1}; clomazone at 1.0 kg ha^{-1}; diclosulam at 35.0 g ha^{-1}; metribuzin at 0.48 kg ha^{-1}; sulfentrazone at 0.6 kg ha^{-1}; sulfentrazone + diuron at 0.245 kg ha^{-1} + 0.49 kg ha^{-1}; and a control without residual herbicide.

Experiment 4 was conducted in a randomized block design with four replications, using a 7x2+2 factorial arrangement, with seven herbicidal treatments applied before the soybean sowing, combined with one of two treatments at post-emergence of soybean, and two controls, one without weed control, and other with manual hoeing from sowing to crop canopy closure.

The herbicides evaluated were 2,4-D at 1.47 kg ha^{-1} + glyphosate at 1.44 kg a.e. ha^{-1}; 2,4-D at 1.47 kg ha^{-1} + glyphosate at 1.44 kg a.e. ha^{-1} + diclosulam at 25.2 g ha^{-1}; flumioxazin at 50.0 g ha^{-1} + glyphosate at 1.44 kg a.e. ha^{-1} + mineral oil at 0.5%; chlorimuron-ethyl at 25.0 g ha^{-1} + glyphosate at 1.44 kg a.e. ha^{-1} + mineral oil at 0.5%; sulfentrazone at 0.245 kg ha^{-1} + diuron at 0.49 kg ha^{-1} + glyphosate at 1.44 kg a.e. ha^{-1}; carfentrazone-ethyl at 22.5 g ha^{-1} + clomazone at 0.9 kg ha^{-1} + glyphosate at 1.44 kg a.e. ha^{-1}; chlorimuron-ethyl at 20.6 g ha^{-1} + flumioxazin at 60.0 g ha^{-1} + glyphosate at 1.44 kg a.e. ha^{-1} + mineral oil at 0.5%, combined with post-emergence application of 2,4-D at 1.14 kg ha^{-1} + glyphosate at 0.82 kg a.e. ha^{-1}, or glyphosate applied single at 1.2 kg a.e. ha^{-1}, at 24 days after sowing.

The common names, trade names, formulations, and manufacturers of the herbicides, and the rates of active ingredient (a.i.) or acid equivalent (a.e.) per hectare used are shown in Table 1.

The areas of the plots were 15.0 m^2 (3.0 × 5.0 m) in Experiments 1 and 4, and 20 m^2 (4.0 × 5.0 m) in Experiments 2 and 3, with subplots of 10 m^2 (2.0 × 5.0 m).

In Experiments 1 and 4, fleabane plants were at full reproductive stage during the first application of herbicides, presenting flower and seed production, and density of 45 and 42 plants m^{-2}, respectively. In Experiment 2, fleabane plants were at the flowering stage, presenting no visible seed production, and density of 62 plants m^{-2}. In Experiment 3, fleabane plants were at the full reproductive stage, presenting flower and seed production, and density of 60 plants m^{-2}.

Table 1 - Common and trade names of the herbicides, herbicide formulation, herbicide rate in active ingredient (a.i.) or acid equivalente (a.e.), and name of the herbicide manufacturer

Herbicide		Formulation[1]	Rate[2] (g L^{-1} - a.i/a.e)	Manufacturer
Common name	Trade name			
2,4-D	DMA	SL	670	Corteva
2,4-D	Enlist Colex-D	SL	456	Corteva
2,4-D Glyphosate	Enlist Duo Colex-D	SL	195 205	Corteva
Atrazine	Gesaprim 500	SC	500	Syngenta
Carfentrazone-ethyl	Aurora 400 EC	EC	400	FMC
Carfentrazone-ethyl + Clomazone	Profit	EC	15 600	FMC
Chlorimuron-ethyl	Classic	WG	250	Corteva
Clomazone	Gamit Star	EC	800	FMC
Diclosulam	Spider 840 WG	WG	840	Corteva
Flumioxazin	Flumyzin 500	WP	500	Sumitomo
Glufosinate-ammonium	Finale	SL	200	BASF
Glyphosate	GlizMax Prime	SL	480	Corteva
Metribuzin	Sencor 480	SC	480	Bayer
Mineral oil	Assist	EC	756	BASF
Saflufenacil	Heat	WG	700	BASF
Sulfentrazone	Boral 500 SC	SC	500	FMC
Sulfentrazone + diuron	Stone	SC	175 350	FMC
Vegetable oil	Aureo	EC	720	Bayer

[1] EC- Emulsifiable concentrate, SC- Suspension concentrate, SL- Soluble (liquid) concentrate, WG- Water dispersible granules, WP- Wettable powder. [2] Rates of glyphosate and 2,4-D are expressed as the acid equivalent (a.e.), and the other products as the active ingredient.

The herbicides were applied using a CO_2-pressurized backpack sprayer at constant pressure (2.0 kgf cm^{-2}), equipped with a spray boom with four or six flat jet nozzles (TTI110015; Teejet®, Wheaton, USA), depending on the plots' width, spaced 0.5 m apart, with an application rate of 150 L ha^{-1}. The meteorological conditions at the time of applications are shown in Table 2.

In Experiment 1, adult fleabane control was evaluated visually at 7 (November 13, 2018) and 29 (December 05, 2018) days after the first application (DAFA). New fleabane emergence events in the plots were evaluated at 29, 57 (January 02, 2019), and 86 (January 31, 2019) DAFA. Grain yield not was evaluated in Experiment 1 due to flaw in the soybean stand. In Experiment 2, adult fleabane control and seedling emergence were evaluated at 7, 15, 28, and 44 DAFA. In Experiment 3, adult fleabane control and seedlings emergence in the subplots were evaluated at 35, 133 (September 23, 2019), and 207 (December 07, 2019) DAFA. In Experiment 4, adult fleabane control was evaluated visually at 10 (December 03, 2019), 33 (December 26, 2019), and 58 (January 22, 2020) DAFA; and new fleabane emergence events were evaluated at 33, 58 and 129 (March 31, 2020) DAFA.

Number of soybean plants, crop grain yield, and plant grain yield were evaluated at the end of the crop cycle, in April 02, 2020. The plants of the evaluation area (three 4-meter rows) of each plot were counted and mechanically harvested; the grain moisture was corrected to 13%. The adult fleabane control was evaluated visually, using a scale of grades of 0% to 100%, in which zero represents the absence of visual injuries, and 100 represents the death of plant (SBCPD, 1995). The new emergence events were evaluated by counting the seedlings in two areas of 0.45 m^2, randomly chosen in the evaluation area of the plots or subplots.

The data were subjected to the F test by analysis of variance, when the interactions were significant ($p<0.01$ or $p<0.05$), they were tested, and the treatments were compared by the Tukey's test at 5% probability level. The controls without herbicide application were not included in the statistical analysis and served only for the development of control grades, except in Experiment 3, for which the control was included in the analysis statistical. In Experiment 4, the controls, with infested and manual hoeing, were compared to the chemical treatments of interest through orthogonal contrasts.

3 Results and Discussion

In Experiment 1, the rainfall depth was 74.4 mm over the 15 days before the first burndown, and 114.5 mm between the first and second burndown. The rainfall depth before these applications was enough to reestablish the development and metabolic activity of the weeds, mainly in the first burndown. In addition, the moisture was satisfactory for the full performance (absorption and translocation) of herbicides.

The herbicides had significant effect on the control of adult fleabane plants at 7 days after the first application (DAFA). Saflufenacil + glyphosate were the most efficient herbicides (89%), differing from the other treatments, which showed control below 47% (Table 3). The additional application was done at 7 DAFA because of the effect of treatments in the first application. The interaction herbicides × additional application was significant at 29 DAFA and showed that the lowest control for the additional application was 96%, and no significant difference between herbicidal treatments (Table 4). However,

Table 2 - Date, time, temperature of air and of soil, air relative humidity (ARH), wind speed (WS), and nebulosity (NEB) at the time of applications of herbicides in the four experiments

Application	Date	Time	Temperature (ºC)		ARH	WS	NEB
			Air	Soil	(%)	(km h^{-1})	(%)
			Experiment 1				
First	11/06/18	09:00-10:45	23.1-23.4	24.5-24.5	82-81	4.6-9.6	95-100
Second	11/13/18	08:20-09:00	22.8-22.6	24.5-25.5	84-85	0	90-80
			Experiment 2				
First	03/12/19	08:30-09:20	24.4-24.0	23.5-24.5	79-83	4.5-3.5	0
Second	03/19/19	08:48-09:10	25.8	24.5	84	0	0
			Experiment 3				
First	04/08/19	10:50-11:10	25.1-27.1	25.5-24.5	88-82	0	60-40
Second	04/16/19	09:20-10:15	27.1-26.7	24.5-26.5	82-81	0	90-70
			Experiment 4				
First	11/23/19	09:15-10:35	26.9-26.0	26.5-25.5	70-59	0-2,1	20-50
Second	12/27/19	08:40-09:45	24.4-24.0	24.2-24.5	75-67	8.6-6.1	40

Table 3 - Control (%) of fleabane plants (*Conyza* sp.) at 7 days after the first application, in the same day of soybean sowing, as a function of first application of herbicides for burndown before the sowing of the crop - Experiment 1

Herbicides - first application(1)	Control (%) - 7 DAFA
1. 2,4-D + glyphosate	46.9 b
2. Carfentrazone-ethyl + glyphosate	25.0 d
3. Flumioxazin + glyphosate	38.1 c
4. Saflufenacil + glyphosate	88.8 a
5. Glyphosate	20.0
6. Control treatment	0.0
MSD	7.7
F of herbicides	197.6**
CV (%)	11.2

(1) Treatments with glyphosate and the control were not included in the statistical analysis; mineral oil at 0.5% was used in the treatments 2, 3, and 4. Means followed by the same letter in the column are not significantly different by the Tukey's test at 5% probability. ** significant at 1% probability level by the F test in the analysis of variance; MSD = Minimum significant difference.

two groups were formed without the second application, with the most efficient (100% control) for saflufenacil + glyphosate, and controls between 86% and 89%. Thus, the additional application of glufosinate-ammonium had advantages for fleabane management when combining glyphosate with 2,4-D, carfentrazone-ethyl, and flumioxazin.

Glyphosate applied single (treatment 5) resulted in 82% control, but with 75% fleabane control. This confirmed that most fleabane plants died naturally in early December due to the end of their biological cycle, which was accelerated by some treatments. The highest plant control for glyphosate compared to control was probably due to presence of individual susceptible to the herbicide in the population. However, plants of all treatments had already produced seeds, which were added to soil seed bank.

Table 4 - Control (%) of fleabane plants (*Conyza* sp.) at 29 days after the first application (DAFA), 22 days after soybean sowing, as a function of herbicide application for burndown (first and additional application) before the sowing of the crop – Experiment 1

Herbicides - first application(2)	Additional application(1) With	Additional application(1) Without
	Control (%) - 29 DAFA	
1. 2,4-D + glyphosate	99.4 a A	88.1 b B
2. Carfentrazone-ethyl + glyphosate	98.8 a A	88.8 b B
3. Flumioxazin + glyphosate	96.2 a A	85.6 b B
4. Saflufenacil + glyphosate	99.4 a A	100.0 a A
5. Glyphosate	81.9	
6. Control treatment	75.0	
MSD (row)	4.9	
MSD (column)	6.6	
$F_{Herbicides \times additional}$	5.7**	
CV (%)	3.6	

(1) Additional application with ammonium-glufosinate at 7 days after the first one; (2) treatments with glyphosate and the control were not included in the statistical analysis; mineral oil at 0.5% was used in the treatments 2, 3, and 4. Means followed by the same uppercase letter in the rows (comparing additional application within each treatment of first application), or lowercase letter in the column (comparing treatments with and without additional application) are not different by the Tukey's test at 5% probability. ** significant at 1% probability level by the F test in the analysis of variance; MSD = Minimum significant difference.

Regarding the new emergence events, 5 fleabane plants in the evaluation area (12 m^{-2}) of one of the replications of the treatment with flumioxazin were found at 29 DAFA, day before 2,4-D + glyphosate application in the area. No new fleabane plants emerged in the other replications and treatments. The absence of new fleabane plants in the plots also was also evaluated at 57 and 86 DAFA.

The biological cycle of the fleabane plants ended in November and December; the emergence of new plants was low and insignificant in November to January compared to the emergences in the other evaluations. Thus, burndown of adult fleabane plants at the reproductive stage is unnecessary, depending on the soybean sowing time, since their coexistence with soybean will be by short and their seed production will have already occurred. Thus, increases in soil seed bank will not be avoided. The best time for fleabane management in the study region, focused on control of plants and decrease their seeds in the soil is in the first six months of the agricultural year, when these species show higher emergence pressure in the areas.

Fleabane seed production can reach of 85.000 to 230.000 seeds per plant, depending on the species and plant size (Bajwa et al., 2016; Ottavini et al, 2019; Weaver, 2001). According to Dauer et al. (2007), 99% of the seeds produced are found at 100 m of the mother plant and the remainder is dispersed up to 500 m from the original population, and farter that this sometimes; thus, the existence of plants with seeds in agricultural fields is worrying due to increases in soil seed bank and dissemination intra and inter field.

Any management with herbicides in irrigated or rainfed autumn-winter crop seasons assist in fleabane management. When the area is fallow, chemical treatments after soybean or winter maize harvest will be more effective for fleabane management than applications at pre-sowing of the summer crop.

Therefore, Experiment 2 was installed in an area that was fallow in the summer, adjacent to the area of Experiment 1, presenting density of 62 fleabane plants per square meter, with emergence starting in February 2019. The objective was to conduct evaluations in the autumn-winter season and confirm the efficiency of herbicides evaluated in Experiment 1, including glufosinate-ammonium applied single.

The herbicides presented differences at 7 DAFA; the most efficient treatments were saflufenacil + glyphosate, and glufosinate-ammonium (Table 5). The following evaluation showed significant interaction, which was tested with the additional application and showed better control for saflufenacil + glyphosate, and glufosinate-ammonium, with no significant differences from 2,4-D + glyphosate (Table 6). The additional application shoed advantages for treatments with 2,4-D, carfentrazone, and flumioxazin.

Table 5 - Control (%) of fleabane plants (*Conyza* sp.) at 7 and 44 days after the first application (DAFA) of herbicides in the plots - Experiment 2

Herbicides - first application[(1)]	7 DAFA	44 DAFA
	Control (%)	
1. 2,4-D + glyphosate	33.8 c	100.0 a
2. Carfentrazone-ethyl + glyphosate	12.5 d	99.7 ab
3. Flumioxazin + glyphosate	15.0 d	98.8 b
4. Saflufenacil + glyphosate	96.2 a	100.0 a
5. Glufosinate-ammonium	86.2 b	100.0 a
6. Glyphosate	11.2 d	97.6 c
7. Control treatment	0.0	90.0
MSD	8.9	1.1
$F_{Herbicides}$	404.4**	15.4**
CV (%)	9.1	0.7

[(1)] The control treatment was not included in the statistical analyses; mineral oil at 0.5% was used in the treatments 2, 3, and 4, and vegetal oil at 0.2% was used in treatment 5. Means followed by the same letter in the column are not significantly different by the Tukey's test at 5% probability. ** significant at 1% probability level by the F test in the analysis of variance; MSD = Minimum significant difference.

The additional application was important for treatments with carfentrazone, and flumioxazin at 28 DAFA. The most efficient treatments were 2,4-D + glyphosate, saflufenacil + glyphosate, and glufosinate-ammonium, with and without additional application. The treatments with glyphosate applied single, and with additional application, resulted in 78% to 80% control, and the infested Control area had 72% control. These results indicated that the plants' natural senescence begun at 15 DAFA. The seed production per plants treated was not evaluated, since all plants were at the full flowering stage at the time of application.

The stem elongation and flowering stages of the fleabane plants are dependent on photoperiod. The elongation and flowering stage of *C. bonariensis* and *C. canadensis* begun in long daylight period (16 hours) (Zinzolker et al., 1985). According to Bajwa et al. (2016) these species are autogamous as pollinized by insects; and the seeds are mature after three weeks of fertilization.

The last evaluation time showed that the infested control presented 90% control and herbicidal treatments, 97% to 100% control, regardless of the additional application, since the herbicides × additional application interaction was not significant. The plants were at the full flowering stage at the time of first application; thus, the treatments that promoted faster control of plants, avoiding the addition of new diaspores to the soil, were the most efficient for fleabane management in the central Cerrado biome of Brazil, in the medium to long term. In this case, the treatments selected were saflufenacil and glufosinate-ammonium, followed by 2,4-D. The mixture of glyphosate to herbicides aggregate advantages to the control of species of difficult control and grass species.

Table 6 - Control (%) de fleabane plants (*Conyza* spp.) at 15 and 28 days after the first application (DAFA) as a function of interaction of herbicides in the first and second (additional) applications – Experiment 2

Herbicides - first application[(2)]	15 DAFA		28 DAFA	
	Additional application[(1)]			
	With	Without	With	Without
	Control (%)			
1. 2,4-D + glyphosate	95.0 ab A	86.9 b B	98.9 ab A	95.6 a A
2. Carfentrazone-ethyl + glyphosate	90.0 b A	60.0 c B	92.2 b A	83.1 b B
3. Flumioxazin + glyphosate	88.1 b A	56.2 c B	92.2 b A	79.4 b B
4. Saflufenacil + glyphosate	100.0 a A	100.0 a A	100.0 a A	100.0 a A
5. Glufosinate-ammonium	99.8 a A	95.0 ab A	100.0 a A	98.5 a A
6. Glyphosate	57.5 c A	45.0 d B	80.0 c A	78.1 b A
7. Control treatment	20.0		72.5	
MSD (row)	6.4		4.5	
MSD (column)	9.6		6.6	
$F_{Herbicides \times additional}$	17.7**		5.3**	
CV (%)	1.5		2.3	

[(1)] Additional application at 7 days after the first one, in treatments 1 to 5 with glufosinate-ammonium, and treatment 6, with glyphosate; [(2)] the control treatment was not included in the statistical analyses; mineral oil at 0.5% was used in the treatments 2, 3, and 4, and vegetal oil at 0.2% was used in treatment 5. Means followed by the same uppercase letter in the rows (comparing additional application within each treatment of first application), or lowercase letter in the column (comparing treatments with and without additional application) are not different by the Tukey's test at 5% probability. ** significant at 1% probability level by the F test in the analysis of variance; MSD = Minimum significant difference.

New fleabane emergence events in the experimental areas were not found up to 44 DAFA, even in the infested control. The fleabane seed bank of the area had one single emergence event of plants, which were treated with post-emergence herbicides. Although fleabane plants died and dried in the plots, other species were found in the infested control area (*Digitaria* sp., *Eleusine indica*, *Tridax procumbens*), forming a dense soil green cover that hindered the emergence of seedlings. Post-emergence herbicide application, mainly flumioxazin, could have had effect on the soil and inhibit the fleabane emergence; however, no fleabane emerged in the treatments with glyphosate applied single, which has no residual action on the soil and resulted in total or partial control of other weeds species.

Therefore, Experiment 3 was conducted to evaluate other fleabane emergence events, using residual herbicides applied with or without previous burndown of weeds. The objective of this burndown was to eliminate the soil green cover and favor the contact of the herbicide with the soil. The emergence in the control treatment without residual herbicide was assessed, with and without burndown of plants, since decreases or removal of the soil green cover favor the emergence of new plants of fleabane and other species.

The treatments with metribuzin and control without residual herbicide, with previous burndown, had the lowest control percentages at 35 DAFA, with 91% and 89%, respectively (Table 7). Only the treatment with metribuzin resulted in control lower than 90%, without previous burndown. The plants were older at the time of application; thus, the biological cycle logo of most of them ended after the implementation of the experiment. Consequently, increases in soil seeds was not lowered or prevented by any of the treatments.

New fleabane plants in the plots, including in the control without residual herbicide, with or without previous burndown were not found for the fleabane emergence potential over the year up to early December 2019. The dry season, mainly June to October, can explain the absence of new plants (Figure 1). The regrowth of fleabane plants in agricultural areas of the central Cerrado biome of Brazil occurs, in general, as a response to the cut of their shoot, but new emergences do not occur.

Regarding the meteorological conditions during the first three experiments, the rainfall depths in February and March, mainly March, was higher than those in the January and April. However, air temperature (maximum and minimum) was not significantly different in February and March to explain the higher fleabane emergence events in this period, when compared to previous and subsequent months (Figure 1).

The response of germination to temperature is a key adaptative characteristic for annual and biannual winter species, such as those of the genus *Conyza* (Tozzi et al., 2013). Significant differences in the response of germination to temperature have been found for four *C. canadenses* populations from Spain, United Kingdom, Iran, and Canada, probably due to evolutive adaptations to local climates facilitated by agriculture (Tozzi et al., 2013). The estimated minimum temperature for germination and the degree days for growth needed for 50% germination were significantly different between these populations, 8-9.5 ºC for Canada; 9.5-11 ºC for Iran; 12.5-14 ºC for Spain, 11-12.5 ºC for the United Kingdom. Similarly, Brazil is a country with large dimensions and climatic and vegetation diversity, where adaptation and variations in the ecophysiology of these species may also occur.

The fleabane seed bank persistency is reduced in higher depths of the soil profile (Weaver, 2001), and large amounts of plant residues on the soil can be an option for its sustainable management (Bajwa et al., 2016). However, further researches are required to evaluate the seed bank dynamics, longevity, and biology of the persistency and reproduction of species

Table 7 - Control (%) of fleabane plants (*Conyza* spp.) at 35 days after the first application (DAFA) as a function of the interaction of herbicides in the second, and previous burndown applications – Experiment 3

Herbicides - second application	Previous burndown[(1)]	
	With	With
	Control (%) - 35 DAFA	
1. Atrazine	98.1 a A	98.1 a A
2. Clomazone	96.9 ab A	100.0 a A
3. Diclosulam	98.8 a A	100.0 a A
4. Metribuzin	90.6 bc A	87.5 b A
5. Sulfentrazone	100.0 a A	100.0 a A
6. Sulfentrazone + diuron	100.0 a A	100.0 a A
7. Testemunha	88.8 c B	97.5 a A
MSD (row)	4.9	
MSD (column)	7.5	
$F_{\text{Herbicides × additional}}$	2.4*	
CV (%)	3.5	

(1) Previous burndown of plants with glufosinate-ammonium at 7 days before the application of the other herbicides. Means followed by the same uppercase letter in the rows (comparing previous burndown within each treatment of second application), or lowercase letter in the column (comparing treatments with and without previous burndown) are not different by the Tukey's test at 5% probability. ** significant at 1% probability level by the F test in the analysis of variance; MSD = Minimum significant difference.

of the genus *Conyza*, mainly for the Cerrado biome of Brazil.

Experiment 4 was conducted to complement the study on the soybean crops grown after winter maize. The maize grain were harvested and left 10.9 to 18.6 Mg ha^{-1} of plant residues on the soil, which are satisfactory to inhibit germination or emergence of fleabane plants, based on their biological characteristics (Bajwa et al., 2016; Timossi et al., 2018; Vidal et al., 2007; Wu et al., 2007; Zinzolker et al., 1985). However, the fleabane plants in the area had been subjected to an ineffective chemical control in the maize crop, which only had their growth inhibited and their cycle delayed due to the maize canopy closure.

The plants were cut and regrew due to the maize mechanical harvest, increasing their biological cycle (Figure 2). The regrowth of plants was visible in the field in early October and the plants predominated in the area after the stabilization of rainfall events, in later November. Thus, fleabane plants did not emerge after the maize harvest, but regrew after their shoots were cut. Therefore, the amount of maize straw on the soil had no effect on the germination and emergence of plants.

This confirmed that fleabane problems are recurrent in soybean crops, even in the areas with autumn-winter crops, when the chemical management of these species is not efficient in rainfed or irrigated autumn-winter crops.

The chemical treatments applied at pre-sowing or post-emergence of soybean and their interactions had no significant effect on the mean plant population (246,700 plants per hectare), plant grain yield (17.2 g), and crop grain yield (4.2 Mg ha^{-1}) of soybean. However, the orthogonal contrasts showed that they were all different from the infested control, which had lower means, with significant decreases in crop grain yield (61%), plant grain yield (41%), and plant population (34%).

Moreover, the infested control areas had high densities other weeds species, such as *Digitaria* sp., *Cenchrus echinatus, Eleusine indica, Richardia brasiliensis, Euphorbia heterophylla, Bidens* sp., *Chamaesyce hirta, Sida rhombifolia, Tridax procumbens*, and *Commelina benghalensis*. Thus, the effect found for the soybean plants in the infested control areas should not be attributed only to the effect of fleabane plants.

The results of the burndown treatments for the control of adult fleabane plants in the three evaluations differed from each other. The post-emergence treatments and the interaction between the factors were significant only at 58 DAFA (Table 8). The most efficient burndown treatments at 10 DAFA was 2,4-D + diclosulam + glyphosate, with 50% control, not differing from 2,4-D + glyphosate. These treatments resulted in 99% and 95% control, respectively, at 33 DAFA, and were different from the other, which resulted in at most 59% control, whereas the fleabane control in the infested control treatment was 44%.

The beginning of the control of fleabane plants differed between the two years studied when comparing November of the first year and December

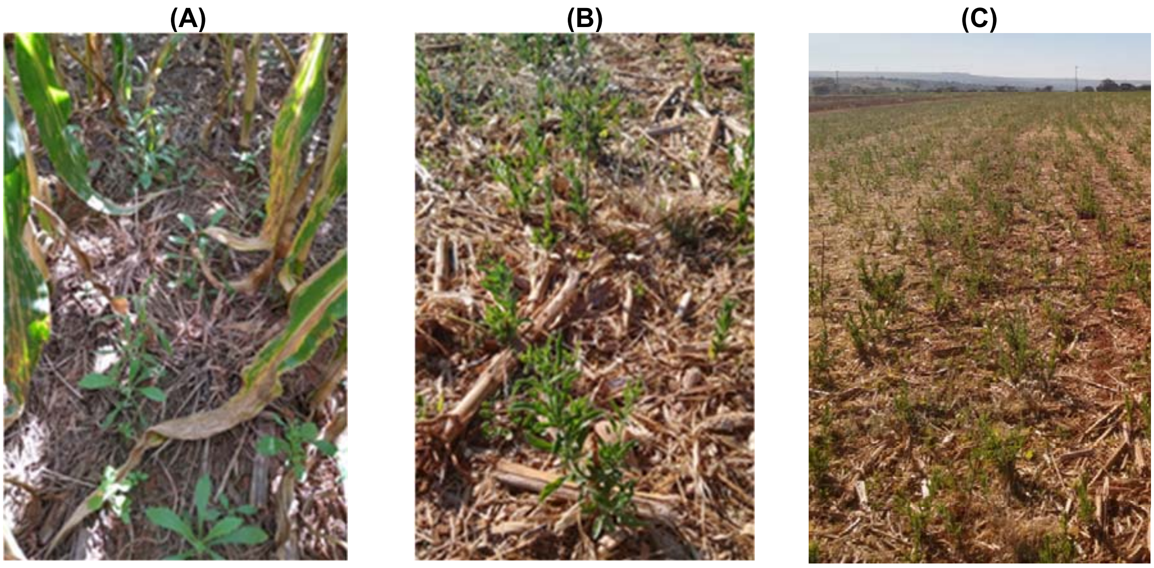

Figure 2 - Growth of fleabane in maize crop (A), regrowth of fleabane plants after the maize harvest (B) and establishment of fleabane plants on the maize straw before soybean sowing (C) – Experiment 4.

Table 8 - Control (%) of fleabane plants (*Conyza* spp.) at 10, 33, and 58 days after the first application (DAFA) as a function of herbicides of the first application (burndown) and the interaction desiccation × application at post-emergence of soybean (POST), a 58 DAFA – Experiment 4

Herbicides - first application[(1)]	Control (%) - DAFA			
	10	33	58	
			2,4-D+ glyphosate	Glyphosate
1. 2,4-D+glyphosate	38.1 ab	94.7 a	100.0 a A	100.0 a A
2. 2,4-D+diclosulam+glyphosate	50.0 a	99.4 a	100.0 a A	100.0 a A
3. Flumioxazin+glyphosate	16.9 cd	39.4 c	100.0 a A	95.6 b B
4. Chlorimuron+glyphosate	28.8 bc	58.8 b	100.0 a A	96.9 ab B
5. Sulfentrazone+diuron+glyphosate	8.8 d	40.0 c	100.0 a A	98.1 ab A
6. Carfentrazone+clomazone+glyphosate	31.2 bc	47.5 bc	100.0 a A	98.8 ab A
7. Chlorimuron+flumioxazin+glyphosate	30.0 bc	56.2 bc	100.0 a A	96.9 ab B
8. Testemunha infestada	0.0	43.8	95.0	
MSD (row)	-	-	2.1	
MSD (column)	14.6	17.4	3.1	
$F_{Burndown}$	16.5**	39.4*	2.7*	
$F_{Burndown \times POST}$	1.2	0.2	2.7*	
CV (%)	32.2	18.0	1.4	

[(1)] The control treatment was not included in the statistical analyses; mineral oil at 0.5% was used in the treatments 3, 4, 6, and 7. Means followed by the same uppercase letter in the rows (comparing post-emergence herbicides within each treatment of burndown), or lowercase letter in the column (comparing treatments of the first application) are not different by the Tukey's test at 5% probability. ** significant at 1% probability level by the F test in the analysis of variance; MSD = Minimum significant difference.

of the second. This was probably due to variations at the beginning and stability of rainfall events in the region, which delayed the implementation of the experiment in the second year.

The infested control areas had 95% control of fleabane in January 22, 2020, at 58 DAFA, when the soybean canopy was already closed. Thus, the crop itself, combined to the weed biology, resulted in almost 100% control of fleabane. All chemical treatments for burndown in this period with application of 2,4-D + glyphosate at post-emergence of soybean resulted in 100% control of the fleabane, similar to treatments with 2,4-D + glyphosate, and 2,4-D + diclosulam + glyphosate in the burndown complemented with post-emergence glyphosate application. The other chemical treatments for burndown complemented with post-emergence glyphosate application resulted in 96% to 99% control. Thus, the benefits of chemical control were null or almost null compared to the natural control of plants.

Regarding the new emergence events in the three times of evaluation (33, 58, and 129 DAFA), no new fleabane emergence occurred in the plots at the soybean harvest, including the controls without herbicides. The infested control had many weeds, mainly grass species, hindering the emergence of new plants, and the control with manual hoeing had a more favored environment for this, due to total absence of weeds. However, at the soybean harvest, the adjacent area to the experiment without soybean plant had fleabane plants with 2 to 4 leaves up to 20 cm height, emerged in previous weeks. Based on the soil seed bank, the potential of new fleabane emergence events in the experiment area was high, but it was not confirmed due to the dense shading of the soybean.

The data obtained in Experiment 4 confirmed the hypothesis that considers the time of emergence and senescence of fleabane plants in the central Cerrado biome of Brazil, and shows the need for adequate chemical management in the autumn-winter, since the biological cycle of these plants (emergence to senescence) presented high variation, from around 90 days to almost 300 days, when the plants were hoed and could regrow, presenting a biannual cycle.

The limiting factor for the emergence of new fleabane plants in agricultural areas of the Cerrado biome was the water deficit that occur from May to September. Despite the thermal conditions and favorable energetic availability to the plants in the dry season (Silva et al, 2008), no new emergence of fleabane was observed. This is consistent with agricultural areas in the Planalto Central region of Brazil, where the fleabane plants infesting areas at pre-sowing of soybean crops emerged at the beginning of the agricultural year and survived due to the poor management of the area, and the biological cycle of plants that presented no signs of stress (chemical or mechanical) from October to November had ended.

4 CONCLUSIONS

This study showed that the highest infestation of fleabane in soybean crops occurred before sowing and was partially or fully controlled by burndown treatments and management at pre-sowing of soybean, which did not prevent the high seed production of the weed. The end of the biological cycle of fleabane plants was in November and December (1st year) and December and January (2nd year). Considering the number of plants per square meter, the most significant fleabane emergence events in the areas occurred in February and March. The treatments with saflufenacil and glufosinate-ammonium, followed by 2,4-D, were the most efficient and fastest for the control of adult fleabane plants.

5 Contributions

The author performed, statistically analyzed the data and wrote the manuscript.

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Nothing to declare.

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