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RESEARCH ARTICLE

Biological and economic efficiency of glyphosate-containing herbicide mixtures for pre-plant burndown control of conyza spp.

Eficiência biológica e econômica de misturas contendo glifosato para controle de buva (conyza spp.) em dessecação pré-semeadura

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Abstract: **Background**: Pre-plant burndown using herbicides is a key practice in no-till cropping systems which has been complicated by the evolution of glyphosate-resistant (R) weed populations in Brazil.
Objective: To evaluate pre-plant burndown weed control efficacy of glyphosate-containing tank mixtures such that novel, cost-effective control options can be determined.
Methods: Glyphosate was sprayed alone or tank-mixed with 2,4-D, flumioxazin, saflufenacil, or ammonium-glufosinate onto nutsedge (*Cyperus* spp.), arrowleaf sida (*Sida rhombifolia* L.), and glyphosate-R *Conyza* spp. populations. Treatments ranged from one (glyphosate only) to up to four active ingredients (a.i.) in the mixture and included an untreated check. Experimental units (15 m^2 plots) were replicated four times and arranged as complete blocks. Weed control efficacy was visually assessed 7-42 days after spraying (DAS) using a 0-100% grading scale and was later combined with treatment costs to evaluate economic feasibility.
Results: Glyphosate controlled nutsedge and arrowleaf sida effectively, scoring the lowest cost per control unit, but mixtures were required for satisfactory (>80%) glyphosate-R *Conyza* spp. control. Mixing glyphosate and 2,4-D resulted in 78% control at 42DAS while incurring the lowest price per control unit. However, a glyphosate+ ammonium-glufosinate tank-mix was the only two-way mixture to match control results of three- or four -way mixtures, resulting in 98% control.
Conclusions: Mixtures are required for proper glyphosate-R *Conyza* spp. control. Despite an increase in overall costs, tank-mixing herbicides with different modes of action should not be completely disregarded, especially in a scenario where resistance can develop under recurrent selection pressure.

Keywords: 2,4-D, ammonium-glufosinate, herbicide resistance, horseweed, saflufenacil.

Resumo: **Introdução**: A dessecação pré-semeadura é prática fundamental para cultivo em semeadura direta, a qual foi complicada pela seleção de populações de plantas daninhas resistentes ao glifosato no Brasil.
Objetivo: Avaliar a eficácia de controle de infestantes usando misturas de tanque contendo glifosato em dessecação, visando-se determinar opções inovadoras com bom custo-benefício.
Métodos: Glifosato foi pulverizado isoladamente ou em mistura ao 2,4-D, flumioxazina, saflufenacil ou amônio-glufosinato sobre tiririca (*Cyperus* spp.), guanxuma (*Sida rhombifolia* L.), e buva (*Conyza* spp.) resistente ao glifosato. Tratamentos consistiram de somente um (glifosato) até misturas com quatro ativos, e tratamento-controle. Unidades experimentais (parcelas de 15 m^2) com quatro repetições seguiram delineamento em blocos casualizados. Controle de plantas daninhas foi avaliado visualmente entre 7-42 dias após aplicação (DAA) utilizando escala 0-100%, sendo posteriormente combinado com custos de cada tratamento buscando-se determinar viabilidade econômica.
Resultados: Glifosato eliminou eficientemente tiririca e guanxuma, resultando no menor custo unitário de controle, porém somente misturas de tanque controlaram buva resistente satisfatoriamente (>80%). Mistura entre glifosato e 2,4-D resultou em 78% de controle aos 42DAA e no menor custo por percentual de controle de buva. Contudo, glifosato+amônio-glufosinato foi a única mistura com dois ativos a igualar resultados obtidos para misturas de três ou quatro ativos, atingindo controle de 98%.
Conclusões: Misturas de tanque controlam buva resistente ao glifosato. Apesar de maiores custos, misturas de herbicidas de diferentes mecanismos de ação não deveriam ser desconsideradas, especialmente em um cenário em que a resistência pode desenvolver-se sob frequente pressão de seleção.

Palavras-chave: 2,4-D, amônio-glufosinato, buva, resistência a herbicidas, saflufenacil.

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1. Introduction

Herbicides are phytotoxic molecules that have been used for managing weed species since the early 1940s. Pre-plant burndown applications using post-emergence herbicides are a common agricultural practice worldwide and aim at ensuring a weed-free environment that favors the growth and elevated yield of crop plants (Vink et al., 2012; Zandoná et al., 2018). This practice is key in no-tillage systems due to the lack of soil disturbance - which could eliminate weed plants and allow for selective, cost-effective weed management in major summer crops such as soybean and maize.

Effective pre-plant burndown applications, as suggested, are performed before crop sowing and are the first step in any successful weed management program. This practice is intended to eliminate all plants growing in the field while not leaving any residues which could harm crop plants upon sowing. When performed with enough anticipation of crop sowing, pre-plant burndown will create a favorable environment for crop plants to grow and exhibit their maximum yield potential (Vink et al., 2012; Zandoná et al., 2018).

Proper management of herbicide-resistant and tough-to-kill weed species is often the goal of pre-plant burndown herbicide applications. Herbicide resistance is defined as the inherited ability of a given weed biotype or population to survive after exposure to herbicide rates that are lethal to wild plants within that species (Pedroso et al., 2016). In Brazil, the group of tough-to-kill weeds is comprised of herbicide-resistant as well as herbicide-tolerant species such as nutsedge (*Cyperus* spp.) and arrowleaf sida (*Sida rhombifolia* L.), whose occurrence in fields is common (Fleck et al., 2004; Silva et al., 2009; Santos et al., 2018;). These have been shown to compete effectively with summer crops for essential resources (Ulguim et al., 2019) and often present glyphosate tolerance depending on growth stage, requiring the use of herbicides within different modes of action (or the use of sequential applications) for proper control. Yellow nutsedge (*Cyperus esculentus* L.) and purple nutsedge have been reported to decrease soybean yields by 12% and 34%, respectively, depending on infestation levels and control timing (Nelson; Smoot, 2010; Das et al., 2014). Since average soybean yields in Brazil are currently centered around 3,500 kg ha^{-1}, such interference represents a major net monetary loss considering current soybean trade values.

Very few weed species, however, have received as much attention and scrutiny as those in the *Conyza* genus (Asteraceae; commonly named horseweed or fleabane). These are frequently found in winter wheat fields as their seeds commonly germinate in colder months, but mostly hinder summer crop sowing due to the presence of well-developed plants at the time of pre-plant burndown applications (Agostinetto et al., 2018). According to Trezzi et al. (2015), *Conyza* spp. control must be performed early in the growing season to avoid soybean yield losses of up to 40% or higher. Interestingly, economic thresholds for *Conyza* spp. control as low as 0.5 plants m^{-2} has been reported, a clear indication of these species´ noxiousness and competitive ability.

Worryingly, to date herbicide-resistant populations have been confirmed in all three major *Conyza* species which occur in Brazil – namely *Conyza sumatrensis* (Retz.) E.Walker, *Conyza canadensis* (L.) Cronquist, and *Conyza bonariensis* (L.) Cronquist, mainly affecting the efficacy of glyphosate, and currently to a much lower extent 2,4-D, and saflufenacil herbicides (Heap, 2022).

Combining the use of herbicides displaying different sites of action with other integrative weed management approaches is widely recognized as key to ensuring cost-effective, sustainable weed management in agricultural fields. In this scenario, effective pre-plant burndown operations are key to ensure optimum conditions for crop sowing, while the adoption of crop rotation practices combined with the use of herbicide mixtures and different herbicide modes of action (standard herbicide stewardship practices) can be seen as major steps towards more sustainable agriculture (Pedroso et al., 2016).

A wide range of information must be taken into account when it comes to determining which agricultural pesticides to add to a weed management program, mainly costs. Soybeans and maize profitability are largely impacted by machinery usage (mainly acquisition, fuel, and maintenance costs) as well as costs associated with purchasing, spraying, and disposal of pesticides, including herbicides (Artuzo et al., 2018). However, managing herbicide-resistant weed populations generally incurs higher production costs – mostly related to the usage of more expensive herbicides and/or the need for extra applications (Hurley; Frisvold, 2016), and thus each application must be carefully planned regarding not only its biological efficacy (i.e. ability to control weed plants), but also its economic efficiency.

At the present work, our goals were to evaluate weed control efficacy achieved by applications of several herbicide mixtures containing glyphosate in pre-plant burndown, allowing us to determine which options achieve satisfactory weed control levels while also being economically viable from a summer crop weed management program standpoint. This information can aid growers to decide which products to choose and how these will perform when it comes to controlling major weed species in Brazil.

2. Material and Methods

Experimental site. Field trials were conducted at the start of the 2016/17 season in an experimental field located in Itaara, Rio Grande do Sul State, Brazil (29º34'54.0"S; 53º48'26.8"W). Soils in the experimental area were classified as *Neossolo litólico* (Santos et al., 2018), and soil analysis indicated average soil organic matter and clay percentages of 3.4 and 27.0, respectively.

The experimental area has been cultivated with soybean and was left fallow between soybean harvest (March) and the start of the trial (October). This allowed for a worst-case scenario situation in which weeds were undisturbed and left allowed to grow from crop harvest to pre-plant burndown performed on the following growing season, incurring extra difficulties for proper weed control before summer crop sowing due to large weed plant sizes and overall development. Importantly, *Conyza* species in this site were previously identified as a 50:50 mix of *C. bonariensis* and *C. canadensis* based on plant morphology following Lazaroto et al. (2008).

glyphosate-containing herbicide mixtures. Moreover, one additional treatment consisted of glyphosate sprayed alone to allow for proper weed control efficacy comparisons, hence resulting in 11 treatments (Table 1). As can be seen, up to a total of 4 herbicides were sprayed in combination (four-way tank-mixtures), allowing for the use of multiple herbicide modes of action. Experimental units consisted of 15 m^2 plots repeated four times and randomized as complete blocks design.

Importantly, glyphosate was added to all herbicide treatments (either sprayed alone or mixed with other active ingredients) to approximate real pre-plant burndown operations taking place in the field. That is, even when glyphosate-resistant populations are present, growers still spray herbicides mixtures containing glyphosate due to its low costs and a broad spectrum of weed control (Lopez-ovejero et al., 2013). All herbicides employed at the present study are currently registered for use in maize and soybeans pre-plant burndown and were applied using a CO_2-pressurized backpack sprayer equipped with an XR 110.02 flat-fan nozzle calibrated to deliver 150 L ha^{-1} at 210 kPa.

Variables analyzed. Efficacy of control of nutsedges (*Cyperus* spp.) and arrowleaf sida (*Sida rhombifolia*) was assessed at 7 and 22 days after herbicide spraying (DAS). Concerning *Conyza* spp., an additional assessment was performed at 42 DAS for any weed regrowth to be assessed. Visual control ratings followed a percentage scale, at which 0% indicates lack of any herbicide-induced symptoms, whereas 100% indicates plant death (Frans, 1979).

Table 1. List of treatments employed in this study.

Treatments	Trade names	Mode of action	Rate[7] (l or kg ha^{-1})	Rate[8] (g ai or ea ha^{-1})
1. Untreated control	-	-	-	-
2. Glyphosate[1]	Roundup®[2]	EPSPs[3] Inhibitor	4.0	1440
3. Glyphosate + 2,4-D[1]	Roundup® + U 46®	EPSPs Inh. + Auxin[4]	4.0+1.5	1440+1005
4. Glyphosate + saflufenacil[1]	Roundup® + Heat	EPSPs + Protox[5] Inh.	4.0+0.07	1440+49
5. Glyphosate + flumioxazin[1]	Roundup® + Flumyzin 500®	EPSPs + Protox Inh.	4.0+0.10	1440+50
6. Glyphosate + glufosinate[1]	Roundup® + Finale®	EPSPs + GS[6] Inh.	4.0+3.0	1440+600
7. Glyphosate + 2,4-D + saflufenacil	Roundup® + U 46® + Heat®	EPSPs + Auxin + Protox Inh.	4.0+1.5+0.07	1440+1005+49
8. Glyphosate + 2,4-D + flumioxazin	Roundup® + U 46® + Flumyzin 500®	EPSPs + Auxin + Protox Inh.	4.0+1.5+0.10	1440+1005+50
9. Glyphosate + 2,4-D + glufosinate	Roundup® + U 46® + Finale®	EPSPs + Auxin + GS Inh.	4.0+1.5+3.0	1440+1005+600
10. Glyphosate + 2,4-D + saflufenacil + glufosinate	Roundupv + U 46® + Heat® + Finale®	EPSPs + Auxin + Protox + GS Inh.	4.0+1.5+0.07+3.0	1440+1005+49+600
11. Glyphosate + 2,4-D + flumioxazin + glufosinate	Roundup® + U 46® + Flumyzin 500® + Finale®	EPSPs + Auxin + Protox + GS Inh.	4.0+1.5+0.10+3.0	1440+1005+50+600

[1]Herbicide active ingredients; [2]Roundup Original; [3]5-enolpyruvylshikimate-3-phosphate synthase; [4]Synthetic Auxin;[5]Protoporphyrinogen IX oxidase;[6]Ammonium-glufosinate, a glutamine synthetase inhibitor; [7]liters or kilograms of active ingredient per hectare;[8]grams of active ingredient or acid equivalent per hectare.

Economic analyses were performed for *Conyza* spp. control, since species in this genus, are currently one of the main targets for pre-plant burndown operations in Brazil (Mendes et al., 2021). To this end, data regarding costs for the purchase of each herbicide was gathered in the experimental site surrounding region, which was later adjusted to the actual herbicide rates used (for instance, 4 L ha^{-1} for Roundup Original®, or 70 g ha^{-1} for Heat® herbicide). The costs for each unit (percentage) of *Conyza* spp. control was then obtained and presented at the country´s currency (R$) to aid growers and stakeholders in the decision-making process.

Data analysis. Following O´Neill-Matthews ($p \leq 0.05$) and Shapiro-Wilk ($p \leq 0.05$) tests for data homogeneity and normality, respectively, data were subject to ANOVA ($p \leq 0.05$) and means compared using Scott-Knott test ($p \leq 0.05$), when appropriate. Data analysis was performed on R studio (R Core Team, 2020) using the ExpDes.pt package (Ferreira et al., 2014).

3. Results and Discussion

Results from both O´Neill-Matthews ($p \leq 0.05$) and Shapiro-Wilk ($p \leq 0.05$) tests indicated no need for data transformation, whereas ANOVA results exhibited that differences across treatments means were statistically significant ($p \leq 0.05$). Such indicates that herbicide treatments affected weed control levels differently, as shown in Figure 1.

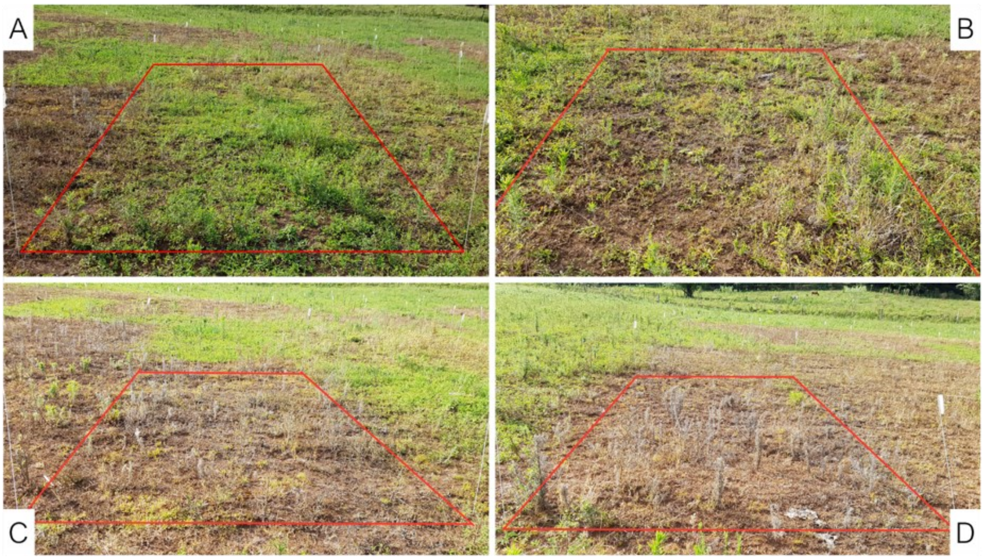

Figure 1. Photos taken 7 days after herbicide spraying (DAS). (A) Weed infestation at one of the untreated (weedy) control plots; (B) Weed control following spraying of glyphosate alone. Note the widespread occurrence of green plants – this is expected due to glyphosate´s slower action relative to other herbicides employed in this study; (C) plot treated with a glyphosate + 2,4-D + glufosinate tank-mix; and (D) plot which had received an application of glyphosate + 2,4-D + glufosinate + flumioxazin. Glufosinate is a faster acting herbicide and thus allowed for greater weed control levels even at 7 DAS, as evidenced by the overall appearance of (C) and (D).

All treatments containing flumioxazin allowed for greater initial (7 DAS) nutsedge (*Cyperus* spp.) control levels; such level was similar to that obtained following spraying of a more complex and expensive four-way mixture containing glyphosate + 2,4-D + saflufenacil + glufosinate (Table 2). However, none of the treatments reached 100% control at 22 DAS and hence some *Cyperus* spp. plants were allowed to grow and set seeds regardless of herbicide application. Interestingly, lower nutsedge control levels were obtained with an application of glyphosate + 2,4-D relative to spraying of glyphosate alone. A similar trend was noticed when glyphosate + glufosinate was sprayed with or without the addition of 2,4-D to the spray mixture, in which adding 2,4-D resulted in poorer control levels relative to the use of glyphosate + glufosinate only. Such results suggest that 2,4-D is not an effective tool for nutsedge control. Accordingly, 2,4-D spraying resulted in unsatisfactory control levels of sedges developing in sugarcane (*Saccharum* spp.) fields and did not aid in the control of acetolactate synthase inhibitor (ALS)-resistant smallflower umbrella sedge in rice fields (Etheredge et al., 2009; Tehranchian et al., 2015). Since an application of glyphosate alone was enough to achieve satisfactory (>80%) *Cyperus* spp. control levels – finishing at 91% control at 22 DAS, this treatment is also the most cost-effective option for nutsedges control.

Table 2. Nutsedge (*Cyperus* spp.) and arrowleaf sida (*Sida rhombifolia*) control levels at 7 and 22 days after herbicide spraying (DAS). Numbers represent percentages control values relative to the untreated (weedy) control.

Treatments	*Cyperus* spp.				*Sida rhombifolia*			
	7 DAS		22 DAS		7 DAS		22 DAS	
Untreated control	0	e[1]	0	c	0	e	0	c
Glyphosate	30	d	91	a	35	d	94	a
Glyphosate + 2,4-D	35	c	76	b	47	c	94	a
Glyphosate + saflufenacil	48	c	87	a	97	a	87	a
Glyphosate + flumioxazin	87	a	93	a	97	a	87	a
Glyphosate + glufosinate	70	b	81	a	96	a	62	b
Glyphosate + 2,4-D + saflufenacil	62	b	66	b	82	b	93	a
Glyphosate + 2,4-D + flumioxazin	87	a	84	a	71	b	87	a
Glyphosate + 2,4-D + glufosinate	67	b	70	b	73	b	91	a
Glyphosate + 2,4-D + saflufenacil + glufosinate	80	a	76	b	96	a	100	a
Glyphosate + 2,4-D + flumioxazin + glufosinate	86	a	85	a	91	a	100	a
CV (%)	21.26		16.01		10.73		10.08	

[1]Significantly different means following results from Scott-Knott testing (p≤0.05) are indicated by different lowercase letters within a column.

Most herbicide treatments controlled arrowleaf sida (*Sida rhombifolia*) effectively (>80% control) at the end of this species´ evaluation period (Table 2). Unlike previous results for *Cyperus* spp., some treatments were able to eliminate all arrowleaf sida plants, as observed for the only two treatments containing four herbicides in the spray mixture (glyphosate + 2,4-D + saflufenacil + glufosinate or flumioxazin replacing saflufenacil in the tank-mix). Such is extremely desirable from a weed management standpoint, as no weed plants could grow and produce seeds in those treatments. A single arrowleaf sida plant has been shown to produce up to 28,000 seeds (Fleck et al., 2003), hence enriching the soil seed bank and leading to severe weed infestations in the future. Results also suggest some level of antagonism between glyphosate and glufosinate for control of this species, given that control percentages recorded following spraying of a glyphosate + glufosinate tank-mix were significantly lower than those obtained when glyphosate was sprayed alone. Some species within the *Sida* genus can propagate vegetatively and regrow following complete plant desiccation (Nahm; Morhart, 2018), resulting in widespread plant regrowth and seed production when contact herbicides such as glufosinate are sprayed onto older weed plants such as those in this study. Interestingly, similarly to nutsedge results, spraying of glyphosate alone for arrowleaf sida represented the most cost-effective treatment option, as it resulted in excellent levels of weed control (94%) with greater simplicity (just a single herbicide needed) and, therefore, lower costs. However, in this case, some herbicide mixtures eliminated arrowleaf sida plants completely (reaching 100% control, which had not been the case for any treatment sprayed onto *Cyperus* spp.), and hence such mixtures could present more desirable arrowleaf sida control options as they effectively prevent soil seed bank enrichment.

Glyphosate sprayed alone resulted in poor *Conyza* spp. control levels throughout the trial (Table 3), indicating that *Conyza* spp. populations in the experimental area displayed resistance to this widely-used active ingredient. Glyphosate spraying in this area has been the standard weed management operation for years while other herbicide modes of action were rarely used, allowing for the survival of resistant populations which ultimately reached severe levels of infestation. Accordingly, the use of glyphosate sprayed alone is no longer a recommended practice for proper *Conyza* spp. management, as results by Rizzardi et al. (2019) indicated that almost 80% of *Conyza* spp. biotypes collected in Southern Brazil are no longer controlled by a somewhat large glyphosate rate (1,440 g e.a. ha^{-1}). Complete *Conyza* spp. elimination (100% control) was only achieved via spraying of three- (glyphosate + 2,4-D + saflufenacil) or four-way herbicide tank-mixtures treatments; however, control levels achieved via spraying of glyphosate + glufosinate was statistically similar to those, averaging 98% at 42 DAS, despite there only being two herbicides were present in the mix.

Table 3. *Conyza* spp. control levels recorded at 7, 22, and 42 days after herbicide spraying (DAS).

Treatments	7 DAS	22 DAS	42 DAS
Untreated control	0 e[1]	0 e	0 c
Glyphosate	6 e	21 d	2 c
Glyphosate + 2,4-D	56 c	82 b	78 b
Glyphosate + saflufenacil	97 a	69 b	72 b
Glyphosate + flumioxazin	25 d	17 d	1 c
Glyphosate + glufosinate	97 a	97 a	98 a
Glyphosate + 2,4-D + saflufenacil	100 a	100 a	100 a
Glyphosate + 2,4-D + flumioxazin	77 b	50 c	81 b
Glyphosate + 2,4-D + glufosinate	99 a	96 a	87 b
Glyphosate + 2,4-D + saflufenacil + glufosinate	100 a	100 a	100 a
Glyphosate + 2,4-D + flumioxazin + glufosinate	100 a	100 a	100 a
CV (%)	13.83	15.76	21.22

[1]Significantly different means following results from Scott-Knott testing ($p \leq 0.05$) are indicated by different lowercase letters within a column.

Troublingly, at the present study applications of glyphosate + 2,4-D or glyphosate + saflufenacil mixtures resulted in sub-optimum (<80%) *Conyza* spp. control levels at 42 DAS, in agreement with previous results showing that applications of glyphosate + 2,4-D were not sufficiently effective for *Conyza* spp. control (Oliveira Neto et al., 2013). Since these herbicides are commonly tank mixed for improved control of glyphosate-resistant horseweed as well as glyphosate-tolerant weed species, these results seem to suggest that soil seed bank enrichment might still happen due to the survival of some *Conyza* spp. plants when these herbicides are used.

Following the gathering of control data at 42 DAS, an economic analysis was performed to determine actual costs per unit (percentage) of *Conyza* spp. control. This constitutes useful information from a weed management standpoint since it combines information regarding costs related to herbicide acquisition with actual percentage control obtained following spraying at label rates. Cost-per-unit-of-control results (Table 4) are presented in Real (R$; Brazil´s currency) to alleviate US Dollar (USD) to R$ conversion factor fluctuations and facilitate data interpretation. Despite its lower purchase price, glyphosate sprayed alone achieved poor *Conyza* spp. control due to widespread infestation of glyphosate-resistant biotypes (Table 3), hence each unit of *Conyza* spp. control (%) cost R$ 20. The most cost-effective treatment was a glyphosate + 2,4-D treatment combination, which resulted in 78% control at 42 DAS with a total application cost of R$ 72.5 ha^{-1}, thus only requiring R$ 0.90 (90 cents) for each unit (%) of *Conyza* spp. control. Unsurprisingly, such treatment has been the standard option for glyphosate-resistant *Conyza* spp. management in pre-plant burndown, despite presenting a downside: as it did not eliminate all *Conyza* spp. plants, some weed plants which survived the treatment ended up producing seeds, potentially leading to greater difficulty for control down in the following years.

As mentioned previously, spraying glyphosate + glufosinate represented the only option containing 2 active ingredients to match *Conyza* spp. control levels achieved by three- or four-way herbicide mixtures (Table 3). However, this two-way mixture also resulted in greater costs per hectare as well as per unit of *Conyza* spp. control, exceeding those associated with the use of a more complex tank mixture containing glyphosate, 2,4-D, and saflufenacil (Table 4). The latter incurred lower (R$ 1.3 ha^{-1}) costs per unit of *Conyza* spp. control (on a per hectare basis) and total costs estimated in R$ 118 ha^{-1}, whereas glyphosate + glufosinate application resulted in costs nearly R$ 60 above that, for similar *Conyza* spp. control levels – hence its greater costs per unit of weed control.

Table 4. Average purchasing prices for herbicide packages or containers employed in this study, as well as the overall treatment costs on a per hectare basis, and price per unit (%) of *Conyza* spp. control. Calculations considered only *Conyza* spp. control values obtained at the last evaluation date (42 days after treatment spraying).

Treatments	Package or container price (R$)	Treatment costs ha^{-1} (R$)	Price per Unit of control (R$ ha^{-1})
Roundup Original	12.5[1]	50.0	20.0
Roundup + U 46	12.5+15.0[1]	72.5	0.9
Roundup + Heat	12.5+299.0[2]	109.8	1.5
Roundup + Flumyzin 500	12.5+45.5[3]	95.5	95.5
Roundup + Finale	12.5.0+47.0[1]	191.0	1.9
Roundup + U 46 + Heat	12.5+15.0+299.0	132.3	1.3
Roundup + U 46 + Flumyzin 500	12.5+15.0+45.5	118.0	1.4
Roundup + U 46 + Finale	12.5+15.0+47.0	213.5	2.4
Roundup + U 46 + Heat + Finale	12.5+15.0+299.0+47.0	273.3	2.7
Roundup + U 46 + Flumyzin 500 + Finale	12.5+15.0+45.5+47.0	259.0	2.6

[1]Average price paid for a 1-liter container;[2]Average price paid for a 350-gram package;[3]Average price paid for a 100-gram package.

It must be mentioned that a dozen new glufosinate-based commercial products have since been released into the Brazilian market (Agrofit, 2021), which in turn is expected to bring prices down significantly. Despite larger costs, a glyphosate + glufosinate tank-mix should not be completely disregarded – instead, including spraying in weed management programs could play a major role in delaying or preventing herbicide resistance evolution, given its exclusive mode of action (inhibition of glutamine synthetase). Such mixture can be expected to be economically feasible within a soybean-maize production system framework due to its ability to effectively manage *Conyza* spp., hence preventing soil seedbank buildup and subsequent severe yield losses in the coming years. Herbicide-resistant weed populations can cause major yield losses in soybean and maize fields, hence negatively impacting profitability. For instance, an average total cost of R$ 92.03 ha^{-1} has been calculated for all herbicide applications taking place in Brazilian Roundup Ready® soybean fields - from pre-plant burndown herbicide spraying to post-emergence and pre-harvest desiccation. Strikingly, an average total cost of R$ 386.65 ha^{-1} can be observed for fields where herbicide-resistant weeds occur - mainly *Conyza* spp. and sourgrass (*Digitaria insularis* (L.) Fedde) (Adegas et al., 2017), which represents a strikingly 420% increase.

It is a noteworthy fact that, despite all resistance cases, glyphosate remains an option for controlling a broad range of weed species, remaining an invaluable tool in agricultural systems worldwide. Lastly, it must be also mentioned that actual costs for herbicide acquisition will vary according to the grower´s location, also decreasing when greater volumes are purchased, incurring overall lower total costs for weed control. Furthermore, herbicide active ingredients are generally sold by several Ag companies and several different formulations are available for purchase, affecting overall costs for weed control. Commercial products employed in the present study were chosen based on efficacy and use by Brazilian summer crop growers. Results presented here demonstrated that spending more on pre-plant burndown applications does not always translate into greater weed control levels, and indicated that decisions regarding actual herbicides to be used must be made by combining information concerning the area´s weed flora, total costs for herbicide acquisition, and expected weed control levels.

Tank-mixing allowed for the use of multiple herbicide modes of actions simultaneously and can be seen as a tool for effectively delaying or preventing herbicide resistance evolution, especially in a scenario in which new cases of herbicide resistance can be expected due to the repeated use of herbicides within the same mode of action and the lack of new herbicidal modes of action in the market.

4. Conclusions

Glyphosate sprayed alone effectively eliminated nutsedge and arrowleaf sida populations. However, two- or three-way herbicide mixtures were required for satisfactory (>80%) glyphosate-resistant *Conyza* spp. control, increasing costs while allowing for a weed-free environment for crop seeding. A glyphosate + 2,4-D mixture resulted in the lowest costs per unit of *Conyza* spp. control but did not achieve satisfactory control levels (<80%). On the other hand, spraying glyphosate + glufosinate allowed for excellent *Conyza* spp. control levels (>95%) while also increasing total costs significantly.

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