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RESEARCH ARTICLE

Interaction between herbicides, adjuvants and nitrogen fertilizers in *Conyza* spp. control

Interação entre herbicidas, adjuvantes e adubos nitrogenados para o controle de *Conyza* spp.

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Abstract: **Background**: The use of adjuvants and nitrogen fertilizers mixed with herbicides can positively or negatively affect the control efficiency of weeds, such as horseweed.
Objective: Our objective was to evaluate the interference of adjuvants and nitrogen fertilizers added to the application mixture, on the efficiency of the herbicides saflufenacil and glufosinate ammonium in controlling horseweed.
Methods: The experiments were carried out from March to July 2019 under protected cultivation conditions in a greenhouse. Conducted in a randomized block design, 5x3 factorial design, with four replications. Factor A is composed of the herbicides saflufenacil (EI) (70 g ai ha^{-1}) and ammonium glufosinate (500 g ai. ha^{-1}) (EII) alone and in mixture with adjuvants Aureo®, Assist®, Dash® and Agral® and factor B is nitrogen fertilizers: urea and ammonium sulfate, plus the control without application. Applications were carried out on plants at the 13-15 cm stage.
Results: Regardless of the adjuvant or nitrogen fertilizer used together with the saflufenacil herbicide, all treatments resulted in satisfactory control of fleabane plants, as did the herbicide alone. The effectiveness of horseweed control with glufosinate was greater when Assist® was used in mixture with ammonium sulfate.
Conclusions: For better horseweed control performance with the herbicide glufosinate, it is not recommended to mix urea or ammonium sulfate with Dash® adjuvant in spray solution.

Keywords: chemical control, herbicide interaction, herbicide application, tank mix.

Resumo: **Introdução**: O uso de adjuvantes e adubos nitrogenados em mistura a calda de herbicidas podem interferir de maneira positiva ou negativa na eficiência de controle de plantas daninhas, como a buva.
Objetivo: Nosso objetivo foi avaliar a interferência de adjuvantes e adubos nitrogenados adicionados à calda de aplicação, na eficiência dos herbicidas saflufenacil e glufosinato de amônio no controle da buva.
Métodos: Os experimentos foram realizados no período de março a julho de 2019 em condições de cultivo protegido em casa de vegetação. Conduzidos em casualização por bloco, esquema fatorial 5x3, com quatro repetições. Sendo o fator A composto pelos herbicidas saflufenacil (EI) (70 g ia ha^{-1}) e glufosinato de amônio (500 g ia. ha^{-1}) (EII) isolados e em mistura com adjuvantes Aureo®, Assist®, Dash® e Agral® e o fator B os adubos nitrogenados: ureia e sulfato de amônio, mais a testemunha sem aplicação. As aplicações foram realizadas em plantas no estádio de 13-15 cm.
Resultados: Independentemente do adjuvante ou do adubo nitrogenado utilizado junto a calda do herbicida saflufenacil, todos os tratamentos resultaram no controle satisfatório das plantas de buva, assim como o herbicida isolado. A eficiência de controle de buva com glufosinato foi maior quando o Assist® foi usado em mistura com sulfato de amônio.
Conclusões: Para melhor desempenho de controle de buva com o herbicida glufosinato, não é recomendado a mistura de ureia ou sulfato de amônio com adjuvante Dash® em calda.

Palavras-chave: controle químico, interação de herbicidas, calda de aplicação, mistura em tanque.

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1. Introduction

Conyza spp. species, also known as horseweed or hairy fleabane, is considered one of the main weeds present in crops, and can be found in the South, Southeast and Central-West regions of the country (dos Reis Duarte et al, 2024). It has the capacity to produce an average of 120 thousand seeds. These plants compete with crops mainly for light, water and nutrients (Medeiros et al., 2021).

The chemical control method has been widely used, but some practices must be adopted to achieve greater control efficiency and avoid an increase in cases of species resistance to herbicides. As an example, management in early stages of development, crop rotation and the use of herbicides with different mechanisms of action should be recommended (Harker et al., 2013).

Agricultural adjuvants are chemical products added to the spraying solution that can have different functions, including reduced losses due to spray drift, run-off, or evaporation (Caixeta et al., 2019), enhancing the quality of the application mixture and absorption of the active ingredient by weeds (Martins et al., 2009).

The incorporation of nitrogen sources into the herbicide mixture, in combination with herbicides such as glyphosate, has been associated with spraying rate reduction, cation antagonism in hard water and improved absorption and translocation of the herbicide molecules (Maschhoff et al., 2000); (Pratt et al., 2003). Research suggests that the use of adjuvants in herbicide mixtures enhances weed control efficacy, such as the increased efficacy observed in controlling *Digitaria insularis* through the application of glyphosate combined with ammonium sulfate + urea (Carvalho et al., 2010).

Urea has been associated with enhanced cuticular penetration of some herbicides in plants, due to the augmented diffusion of herbicide molecules through the leaf and disruption of ester, ether, and dieter bonds in the leaves cutin (Witte et al., 2002). In addition to urea, the incorporation of ammonium sulfate to the spray

mixture has also been associated with improved herbicide effectiveness (Carvalho et al., 2008).

There is limited research on the simultaneous inclusion of nitrogen fertilizers and adjuvants in herbicide spraying mixtures to enhance weed control efficacy. Therefore, the objective of this study was to investigate the impact of adjuvants and nitrogen fertilizers added to the spraying solution on the efficacy of the herbicides saflufenacil and glufosinate of ammonium for *Conyza* spp. control.

2. Material and Methods

The experiment was conducted in a greenhouse located in the experimental area of the Weeds and Pesticides in the Environment Research Group belonging to UFRRJ – Seropédica/RJ. The plants were sown in 300 mL plastic pots filled with a mixture of sand, silt and clay (Table 1). Two essays were performed: Essay I (EI) aimed to investigate the interference of adjuvants and nitrogen fertilizers added to the saflufenacil herbicide mixture (Heat® WG - 70g ai ha^{-1}, BASF), and Essay II (EII) aimed to evaluate the interference of adjuvants and nitrogen fertilizers added to the ammonium glufosinate herbicide (Finale® SL – 500g ai ha^{-1}, BASF). Each essay was conducted in randomized blocks with four replications, in a 5x3 factorial scheme. Factor A consisted of the herbicides saflufenacil (EI) and ammonium glufosinate (EII), both applied individually and mixed with adjuvants at the doses described in Table 2. Factor B included the addition of ammonium sulfate or urea nitrogen fertilizers at the respective doses of 15 g L^{-1} and 5 g L^{-1} (EI) and 2 g L^{-1} and 3 g L^{-1} (EII), along with treatment without the addition of fertilizer to the herbicide in the spray mix. Additionally, an untreated control was maintained in both essays. The doses of nitrogen fertilizers were determined according to the Liming and Fertilization Manual of the State of Rio de Janeiro (Freire et al., 2013).

Table 1. Chemical analysis [a] of soil used in experiments EI and EII in the greenhouse.

Soil depth	Na^+	Ca^{2+}	Mg^{2+}	(H^++Al^{3+})	Al^{3+}	Sa	Si	Cl	V	n	pH	Organic matter	P	K^+
(cm)	$cmol_c/dm^3$					%						$dag.kg^{-1}$	$mg.dm^{-3}$	
0-40	0.046	2.9	1.4	3.9	0.3	77	5	18	53	0.54984	5.53	0.49	8.0	41.0

According to the methodology of Empresa Brasileira de Pesquisa Agropecuária – EMBRAPA, 1997.
Sa: Sand; Si: Silt; Cl: Clay.

Table 2. Treatments and doses of adjuvants, herbicides and nitrogen fertilizers used in essay EI and EII.

Treatments EI	Adjuvant dose (%v/v)	Herbicide dose (g a.i. ha^{-1})	Fertilizer dose (g L^{-1})	Treatments EII	Adjuvant dose (%v/v)	Herbicide dose (g a.i. ha^{-1})	Fertilizer dose (g L^{-1})
1 Untreated	-	-	-	1 Untreated	-	-	-
2 Saflufenacil	-	70g	-	2 Ammonium glufosinate	-	500g	-
3 Saflufenacil + Assist®	0.5%	70g	-	3 Ammonium glufosinate + Assist®	0.5%	500g	-
4 Saflufenacil + Aureo®	0.1%	70g	-	4 Ammonium glufosinate + Aureo®	0.1%	500g	-
5 Saflufenacil + Dash®	0.5%	70g	-	5 Ammonium glufosinate + Dash®	0.5%	500g	-
6 Saflufenacil + Agral®	0.05%	70g	-	6 Ammonium glufosinate + Agral®	0.05%	500g	-
7 Urea	-	70g	5g	7 Urea	-	500g	3g
8 Ammonium sulfate	-	70g	15g	8 Ammonium sulfate	-	500g	2g
9 Saflufenacil + Urea	-	70g	-	9 Ammonium glufosinate + Urea	-	500g	-
10 Saflufenacil + Ammonium sulfate	-	70g	-	10 Ammonium glufosinate + Sulfato de Amônio	-	500g	-
11 Saflufenacil + Urea + Assist®	0.5%	70g	5g	11 Ammonium glufosinate + Urea + Assist®	0.5%	500g	3g
12 Saflufenacil + Urea + Aureo®	0.1%	70g	5g	12 Ammonium glufosinate + Urea + Aureo®	0.1%	500g	3g
13 Saflufenacil + Urea + Dash®	0.5%	70g	5g	13 Ammonium glufosinate + Urea + Dash®	0.5%	500g	3g
14 Saflufenacil + Urea + Agral®	0.05%	70g	5g	14 Ammonium glufosinate + Urea + Agral®	0.05%	500g	3g
15 Saflufenacil + Ammonium sulfate + Assist®	0.5%	70g	15g	15 Ammonium glufosinate + Ammonium sulfate + Assist®	0.5%	500g	2g
16 Saflufenacil + Ammonium sulfate + Aureo®	0.1%	70g	15g	16 Ammonium glufosinate + Ammonium sulfate + Aureo®	0.1%	500g	2g
17 Saflufenacil + Ammonium sulfate + Dash®	0.5%	70g	15g	17 Ammonium glufosinate + Ammonium sulfate + Dash®	0.5%	500g	2g
18 Saflufenacil + Ammonium sulfate + Agral®	0.05%	70g	15g	18 Ammonium glufosinate + Ammonium sulfate + Agral®	0.05%	500g	2g

*a.i.: active ingredient

The treatments were sprayed using a backpack sprayer pressurized with CO_2 equipped with a bar containing four flat-fan XR 110 015 spraying tips spaced at 50 cm intervals. The spraying pressure was maintained at 280 kPa, and a total of 150 L ha^{-1} of spray volume was applied, following the corresponding herbicide labels.

Weed Control assessments were carried out at 7 and 45 days after application (DAA) using a visual control scale ranging from 0 to 100%, where 0% indicated the absence of symptoms and 100% represented plant death (Frans et al., 1986). At 45 DAA, the plants were collected and dried in a forced air circulation oven at a temperature of 60 ± 5 °C until a constant mass was achieved. The shoot dry biomass of plants was determined using an analytical balance. The data were submitted to ANOVA ($p \leq 0.05$), and means compared by Skott-Knott test at 5% probability. Statistical analyzes were performed using the RBIO Statistical Software Program, (Bhering, 2017). All graphs were designed using SigmaPlot software version 12.5. The % mass reduction was determined using the equation: 100-((Mass of treated plants/ Mass of untreated plants)*100).

3. Results and Discussion

Saflufenacil

No interaction was observed between the addition of adjuvants or fertilizers and saflufenacil herbicide on *Conyza* spp. control in essay I (EI). Saflufenacil applied at a dose of 70 g a.i. ha^{-1}, either alone or mixed with various adjuvants and nitrogen fertilizers, resulted in 100% control of *Conyza* spp. plants without further regrowth (Table 3). Hence, the addition of adjuvants and/or nitrogen fertilizers to the application solution of saflufenacil did not interfere with the control of Conyza spp. as observed in this study (Figure 1). This finding is consistent with other studies where saflufenacil (35 g a.i. ha^{-1}) with or without adjuvants provided 100% control of *Conyza* spp., *Commelina benghalensis*, and *Ipomoea triloba* at 28 days after application (DAA) (Castro et al., 2017; Castro et al., 2018). However, it is worth noting the importance of incorporating adjuvants into the spray solution to optimize the herbicide's activity, as plant developmental stages and environmental conditions can influence herbicide efficacy, and adjuvants are essential for several active ingredients (Dalazen et al., 2015).

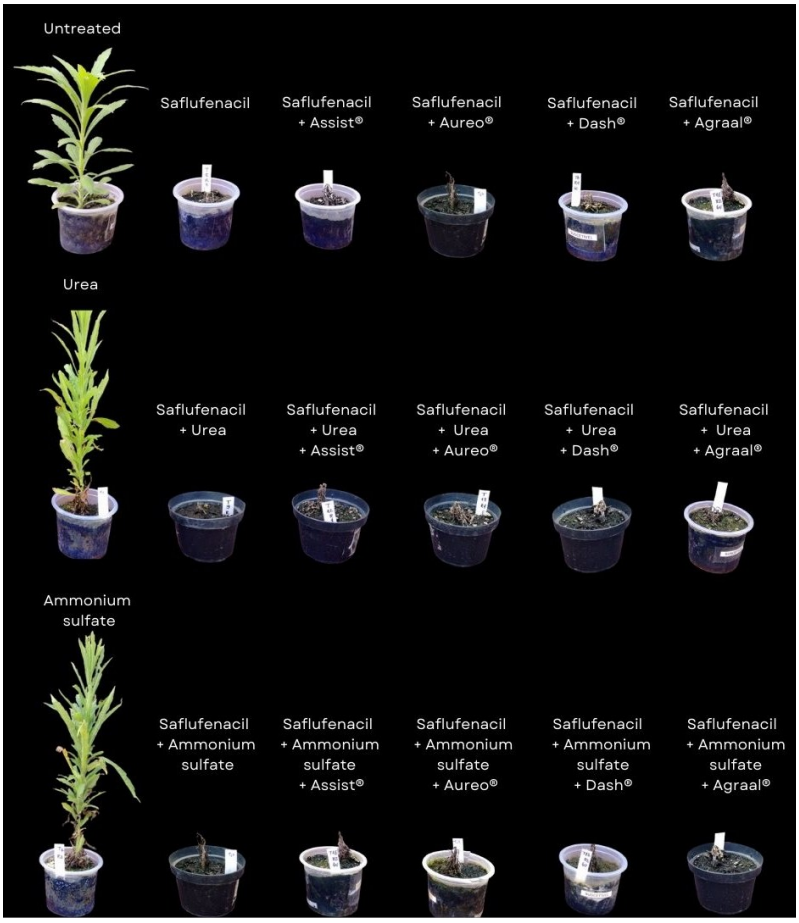

Figure 1. Control evaluation between treatments with saflufenacil, adjuvants and nitrogen fertilizers 45 days after application. PDPA/ UFRRJ, Seropédica – RJ.

Table 3: Control observed for *Conyza* spp. at 7 days after application (DAA) of the saflufenacil herbicide combined with adjuvants Agral®, Assist®, Aureo® and Dash® and the nitrogenous fertilizers ammonium sulfate and urea. Means followed by uppercase letters indicate significant differences between fertilizer addition, while lowercase letters indicate significant between treatments with different adjuvants, based on Skott-Knott test (5% probability).

Treatments	No fertilizer	Ammonium sulfate	Urea
Saflufenacil	100 ns	100 ns	100 ns
Saflufenacil + Agral®	100 ns	100 ns	100 ns
Saflufenacil + Assist®	100 ns	100 ns	100 ns
Saflufenacil + Aureo®	100 ns	100 ns	100 ns
Saflufenacil + Dash®	100 ns	100 ns	100 ns

*ns: The treatments did not differ statistically from each other.

Saflufenacil is a post-emergence herbicide that is commonly recommended for burndown applications and registered for use on several crops including corn, soybeans, cotton, coffee and bananas (Agrofit, 2020). This molecule has become a potential alternative tool to control glyphosate-resistant *Conyza* spp. species (Moretti et al., 2015; Pereira et al., 2016), and has been used alone or in association with other herbicides for weed control (Cesco et al., 2019).

In this study, the effective control of *Conyza* spp. might be associated with the dose (70 g a.i. ha^{-1}) of saflufenacil, which is the label-recommended dose for *Conyza* spp. control in banana and coffee crops (Agrofit, 2020). Previous studies have demonstrated that saflufenacil, at doses ranging from 24.5 to 35 g ai ha^{-1}, has successfully controlled Conyza spp. plants in annual crops (Dalazen et al., 2015). The control was observed up to two weeks after herbicide application, although some regrowth occurred from 21 DAA (Dalazen et al., 2015). Other studies have also demonstrated that *Conyza* spp. control was enhanced with increased doses of saflufenacil, ranging from 25 to 50 g a.i. ha^{-1}, highlighting the dose-dependent response of saflufenacil in controlling these species (Mellendorf et al., 2013).

Saflufenacil is commonly associated with glyphosate and other systemic herbicides for improved weed control, as shown by the notable *Conyza canadensis* control achieved by the mixture glyphosate + saflufenacil (1440 g a.i. ha^{-1} + 56 g a.i. ha^{-1}). In addition to enhancing control performance against target organisms, the use of pesticide tank mixtures can result in cost savings by enabling multiple pesticide applications in a single spray event (Gazziero, 2015).

Ammonium Glufosinate

Interactions between ammonium glufosinate, adjuvants and fertilizers were observed for *Conyza* spp. control and shoot dry biomass in Essay EII (see Tables 4 and 5). Regardless of the various treatments involving the use of ammonium glufosinate, a control rate exceeding 98% was observed at 7 days after application for *Conyza* spp. plants (as shown in Table 4). However, at 45 days after application (Table 5), some treatments exhibited a reduction in control due to plant regrowth. At 45 DAA (as shown in Table 5), the addition of ammonium sulfate and urea to the ammonium glufosinate herbicide alone (without adjuvants) resulted in increases of 8% and 14% in control, respectively, compared to the treatments without these additives (Figure 2). Supporting these findings, a reduction in the shoot dry biomass of *Conyza* spp. was observed by 85% and 88% when ammonium glufosinate was combined with the nitrogenous fertilizers ammonium sulfate and urea in the spray solution, respectively, in comparison to the application of ammonium glufosinate alone being 44% (as indicated in Table 6).

Table 4. Control observed for *Conyza* spp. at 7 days after application (DAA) of the ammonium glufosinate herbicide combined with adjuvants Agral®, Assist®, Aureo® and Dash® and the nitrogenous fertilizers ammonium sulfate and urea. Means followed by uppercase letters indicate significant differences between fertilizer addition, while lowercase letters indicate significant between treatments with different adjuvants, based on Skott-Knott test (5% probability).

Treatments	No fertilizer	Ammonium sulfate	Urea
Ammonium glufosinate	Aa 98	Ab 97.25	Aa 98
Ammonium glufosinate + Agral®	Ba 98	Aa 99.5	Ba 97.5
Ammonium glufosinate + Assist®	Aa 98	Aa 98	Aa 98.5
Ammonium glufosinate + Aureo®	Aa 98	Aab 98.5	Aa 98.5
Ammonium glufosinate + Dash®	Aa 98	Ab 98	Aa 98

C.V = 0.87 (%).

Table 5. Control observed for *Conyza* spp. at 45 days after application (DAA) of the ammonium glufosinate herbicide combined with adjuvants Agral®, Assist®, Aureo® and Dash® and the nitrogenous fertilizers ammonium sulfate and urea. Means followed by uppercase letters indicate significant differences between fertilizer addition, while lowercase letters indicate significant between treatments with different adjuvants, based on Skott-Knott test (5% probability).

Treatments	No fertilizer	Ammonium sulfate	Urea
Ammonium glufosinate	Bb 80	ABb 87.5	Aa 98.25
Ammonium glufosinate + Agral®	Aab 89.5	Aa 100	Aa 87.5
Ammonium glufosinate + Assist®	Aab 92.5	Aa 100	Aa 96.25
Ammonium glufosinate + Aureo®	Aa 100	Aa 100	Aa 90
Ammonium glufosinate + Dash®	Aa 100	Ab 87.5	Bb 70

C.V = 6.17 (%).

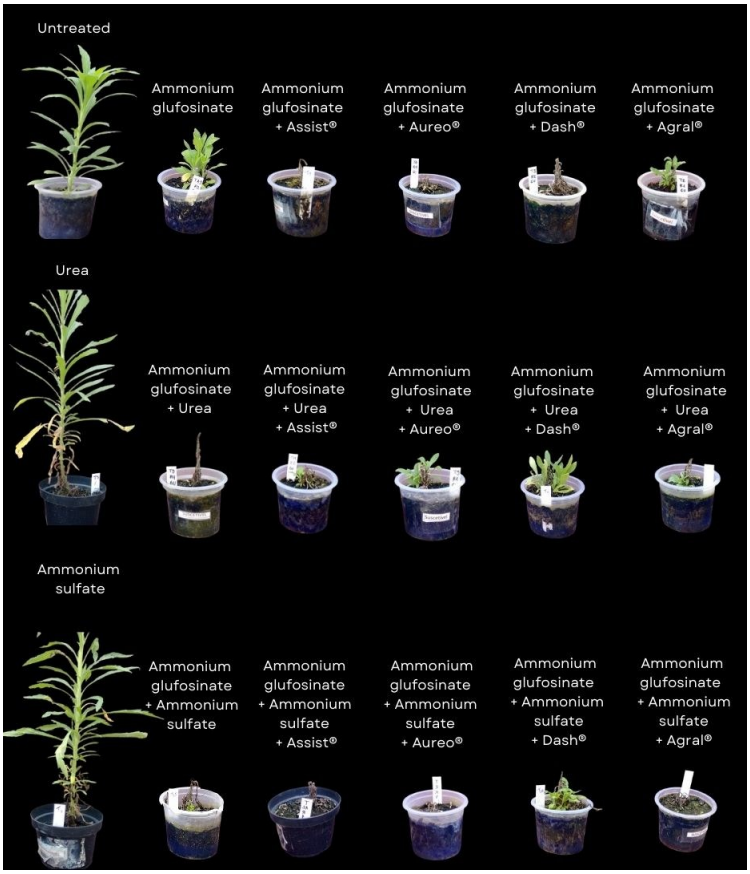

Figure 2. Control evaluation between treatments with ammonium glufosinate, adjuvants and nitrogen fertilizers 45 days after application. PDPA/UFRRJ, Seropédica – RJ.

Table 6. Shoot dry biomass (g) of *Conyza* spp. in response to the application of ammonium glufosinate herbicide combined with the adjuvants Agral®, Assist®, Aureo® and Dash® and the nitrogenous fertilizers ammonium sulfate and urea. Means followed by uppercase letters indicate significant differences between fertilizer addition, while lowercase letters indicate significant between treatments with different adjuvants, based on Skott-Knott test (5% probability).

Treatments	No fertilizer	Ammonium sulfate	Urea
Untreated	Ba 3.45	Aa 4.05	Aa 4.39
Ammonium glufosinate	Ab 1.93	Bb 0.57	Bd 0.49
Ammonium glufosinate + Agral®	Ac 1.02	Cc 0.12	Bc 0.96
Ammonium glufosinate + Assist®	Acd 0.46	Bd 0.02	Acd 0.70
Ammonium glufosinate + Aureo®	Bd 0.01	Bd 0.06	Ac 0.97
Ammonium glufosinate + Dash®	Cd 0.01	Bb 0.73	Ab 2.08

C.V = 4.31 (%).

Studies have demonstrated that the incorporation of ammonium sulfate (2%) in the application solution resulted in enhanced efficacy of glyphosate against certain weed species (Nurse et al., 2008). One theory proposed to explain the observed improvements in control suggests that the inclusion of ammonium sulfate in the glyphosate spraying solution alters the droplet morphology, thereby delaying or inhibiting the crystallization of glyphosate on the leaf surface (Macisaac et al., 1991). As a result, the extended contact time allows the herbicide molecule to properly penetrate the leaves cuticle (Macisaac et al., 1991). Pratt et al. (2003) discovered that among the tested adjuvants for controlling *Abutilon theophrasti* with glyphosate and ammonium glufosinate, the addition of 20 g L^{-1} ammonium sulfate was the most effective.

On the other hand, when glufosinate ammonium + Dash® was applied with the addition of fertilizer to the spray solution, a reduction in *Conyza* spp. control was observed. The addition of ammonium sulfate and urea resulted in 87,5% and 70% control, respectively, whereas glufosinate ammonium + Dash® without fertilizer addition resulted in 100% control and significant biomass reduction (Table 5 and Table 6). The control of *Conyza* spp. with the mixtures of ammonium glufosinate + Agral®, ammonium glufosinate + Assist®, and ammonium glufosinate + Aureo® was not affected by the addition of nitrogen fertilizer to the spray solution at 45 DAA (Table 5). However, in terms of shoot dry biomass, the addition of ammonium sulfate and urea with ammonium glufosinate + Agral® led to a 97% and 78% biomass reduction, respectively, compared to ammonium glufosinate + Agral® alone being 70% (Table 6).

Similar studies have demonstrated that the addition of ammonium sulfate in glyphosate or ammonium glufosinate solutions resulted in enhanced herbicide absorption and translocation, leading to improved control of *Abutilon theophrasti* (Maschhoff et al., 2000; Young et al., 2003). Additionally, research has shown that incorporating ammonium sulfate or a mixture of urea and ammonium sulfate into the spray solution with glyphosate resulted in improved control of *Ipomoea* spp. plants, while the use of nitrogen solutions enhanced the herbicidal activity for *Sorghum halepense* control (Carvalho et al., 2011).

Weak acids, including the herbicides glyphosate, saflufenacil and ammonium glufosinate, can undergo changes in their physicochemical properties due to cations and water pH. These acidic herbicides exhibit maximum absorption and efficiency when the pH is such that 50% of the molecules are dissociated. For example, in the case of glyphosate, a pH range of 3.5 to 5.5 in the spray solution has been shown to enhance its efficacy in controlling *Brachiaria brizantha* (Dan et al., 2009), while for imazethapyr + imazapic, a similar pH range improved the control of red rice (*Oryza sativa*) (Sanchotene et al., 2007). The addition of ammonium sulfate is known to prevent the antagonistic effects of hard water cations and facilitate the cellular uptake of weak acid herbicides (Nalewaja and Matysiak, 1993; Gauvrit, 2003). Therefore, the use of ammonium sulfate can improve the efficiency of herbicides in weed control.

Therefore, the addition of foliar fertilizer and adjuvants to the spray mixture has the potential to impact herbicide control performance. However, it's important to note that different weed species may exhibit varying responses in terms of the herbicide effectiveness when such molecules are incorporated. Caution is required when using nitrogen fertilizers in tank mixes, such as glufosinate ammonium + Dash® with urea, as it reduces control effectiveness, resulting in regrowth, as evidenced by greater dry mass compared to application without urea.

4. Conclusions

The saflufenacil herbicide, when applied at a dose of 70 g a.i. ha^{-1}, demonstrates high efficacy in controlling *Conyza* spp. plants, without any interference from adjuvants or nitrogen fertilizers used in the spraying solution mixture.

In contrast, the use of adjuvants is essential for achieving a successful control of *Conyza* spp. with the ammonium glufosinate herbicide. The addition of urea or ammonium sulfate to the application mixture with ammonium glufosinate herbicide, combined with the adjuvants Agral®, Assist®, and Aureo®, does not affect *Conyza* spp. control.

To achieve better performance in *Conyza* spp. control with ammonium glufosinate, it is not recommended to mix urea or ammonium sulfate with the Dash® adjuvant in the spray solution, as it may lead to a loss of effective plants control.

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