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Performance of glyphosate-based products applied alone and in combination with herbicides in burndown

Performance de produtos à base de glyphosate aplicados isolados e em associações à herbicidas na dessecação

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ABSTRACT - The no-tillage system is a conservation system that helps sustainability and agricultural production. The effectiveness of glyphosate control, applied alone or in combination with other herbicides, can be altered depending on the product's formulation. The objective of the present study was to evaluate the effectiveness of glyphosate in formulations containing different salts and concentrations, applied alone and in combination with other herbicides, in controlling weeds in advanced stages in the pre-sowing burndown operation. The experiment was carried out in the field in an area with a history of high weed infestation. The experiment was conducted in a randomized block design, evaluating eleven treatments and four replicates. The treatments consisted of the application of three glyphosate-based formulations alone and in combination with clethodim and 2,4-D amine herbicides, in addition to a control without herbicide application. The evaluated variables were percentage of weed control and percentage of desiccation. A comparison of means by contrasts was performed to analyze the percentage of weed control. In general, treatments containing products based on glyphosate potassium salt in the composition have slightly better control performance compared to those consisting of glyphosate isopropylamine salt.

Keywords: No-tillage. Conservation system. Weed control. Glyphosate potassium salt. Glyphosate isopropylamine salt.

RESUMO - O sistema de plantio direto é um sistema conservacionista que auxilia na sustentabilidade e a produção agrícola. A eficácia de controle do glyphosate, aplicado isoladamente ou em associação a outros herbicidas, pode ser alterada em função da formulação do produto. O objetivo do presente trabalho foi avaliar a eficácia de glyphosate em formulações contendo diferentes sais e concentrações, aplicado isolado e em associações a outros herbicidas, no controle de plantas daninhas em estádios avançados na operação de dessecação pré-semeadura. O experimento foi realizado a campo em área com histórico de elevada infestação de plantas daninhas. O experimento foi conduzido no delineamento de blocos casualizados, avaliando-se onze tratamentos e quatro repetições. Os tratamentos foram compostos pela aplicação de três formulações à base de glyphosate isolado e em associações com os herbicidas clethodim e 2,4-D amina, além de uma testemunha sem aplicação. As variáveis avaliadas foram porcentagem de controle das plantas daninhas e porcentagem de dessecação. Foi realizado uma comparação de médias por contrastes para analisar a porcentagem de controle de plantas daninhas. De maneira geral, tratamentos contendo produtos à base de glyphosate sal potássico na composição apresentam performance de controle ligeiramente superior em comparação com àqueles constituídos por glyphosate sal de isopropilamina.

Palavras-chave: Plantio direto. Sistema de conservação. Controle de plantas daninhas. Glyphosate sal potássico. Glyphosate à base de sal de isopropilamina.

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INTRODUCTION

Adopting the no-tillage system (NTS) consists of a conservation practice that is governed by three basic pillars, which, when adopted jointly, contribute to a greater sustainability of agricultural production environments, especially in relation to soil protection (BARBOSA et al., 2022). The three pillars of the NTS are the adoption of crop rotation, maintenance of straw (crop residues) and absence of soil turning. However, NTS implementation in large areas only became feasible from the moment in which the values of chemical weed control began to be accessible to producers, since in this situation it became possible to eliminate mechanical practices of weed control, and it was no longer necessary to turn the soil before sowing a given crop (SEGATELLI et al., 2022).

In this context, the herbicide glyphosate has enormous agronomic importance because, as it contains physicochemical properties favorable to use in the pre-sowing burndown of crops, it has become the main active ingredient employed in this operation. Among the physicochemical properties that facilitate the choice of glyphosate as an alternative for pre-sowing burndown, the following features stand out: broad spectrum, as it controls both monocot (narrow leaves) and dicot (broad leaves) species; high translocation after being absorbed (systemic), which allows the control of weeds in advanced stages; and no residual activity in the soil, eliminating the risks of residues affecting the crops to be planted in the area (ALBRECHT et al., 2012).

Glyphosate's mechanism of action is the inhibition of the EPSPs enzyme, which is part of a metabolic process that will result in the synthesis of three essential amino acids for plants (SHANER; BRIDGES, 2003). Currently, glyphosate is the active ingredient with the highest volume of commercialization worldwide, considering all classes of pesticides (TAUHATA et al., 2020). Due to the great importance of glyphosate, as well as its high volume of use in agriculture, different formulations of this active ingredient have been developed by companies over the decades, which had mainly variations as to the glyphosate salt used (SANTOS et al., 2007). Among the main commercial formulations of glyphosate used in Brazil, those that are composed of isopropylamine, ammonium and potassium salts stand out (CARBONARI et al., 2022).

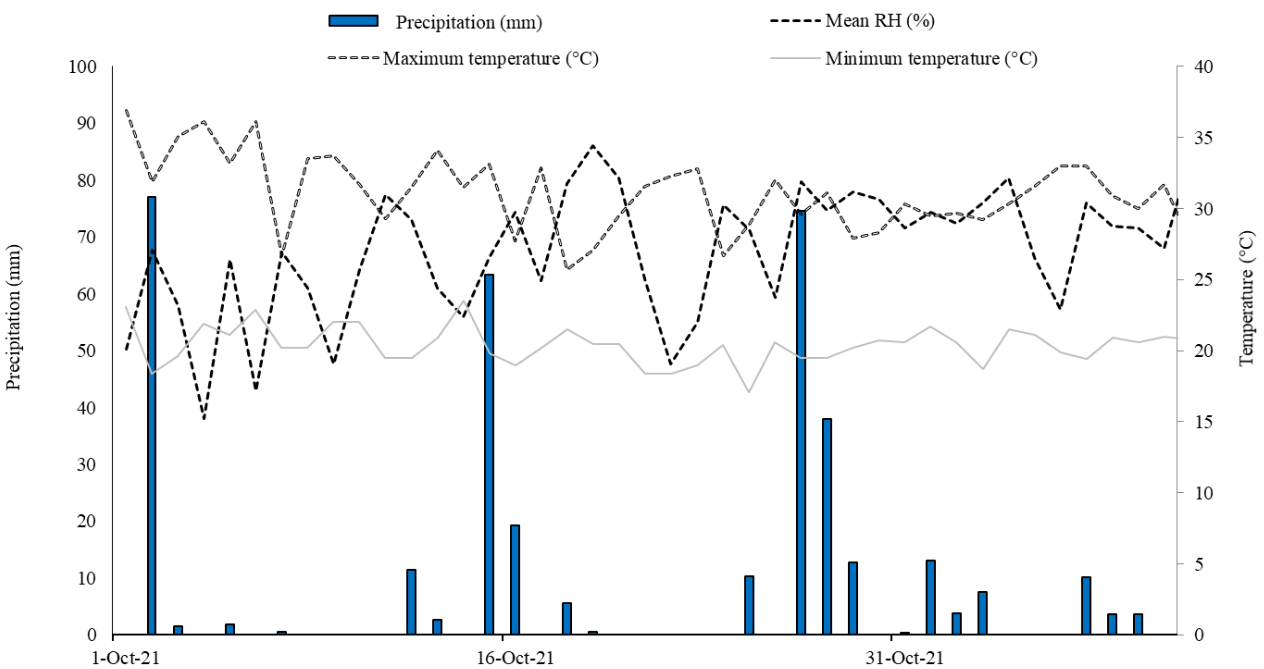
However, despite the high efficacy that glyphosate still has in the control of the various weeds that make up the weed flora, in recent years there has been an increasingly frequent need to combine other herbicides with glyphosate in order to obtain better performances in pre-sowing burndown, due to the existence of naturally tolerant species, as well as those that have biotypes resistant to this active ingredient (TAKANO et al., 2013; KNISS et al., 2022).

By opting for using these herbicide combinations, the producer usually aims to increase the spectrum for controlling weeds present in the area, assist in the management of tolerant and resistant species, and seek the synergistic effect between two active ingredients, which occurs when one herbicide enhances the control action of the other (KRUSE; VIDAL; TREZZI, 2006). In this scenario, it is essential to seek an understanding of how a given herbicide formulation may have its control performance affected as a result of application in combination with other active ingredients.

Given this context, the objective of the present study was to evaluate the efficacy of glyphosate in formulations containing different salts and concentrations, applied alone and in combinations with other herbicides, in controlling weeds in advanced stages in the pre-sowing burndown operation.

MATERIAL AND METHODS

The experiment was set up at an experimental station located in the municipality of Rio Verde, Goiás, Brazil (17º47'12.01" S; 51º00'07.11" W and 766 m of altitude) and conducted from October 8 to November 10, 2021. According to Köppen's classification, the climate of the municipality of Rio Verde is Aw, tropical with dry season, characterized by having more intense rainfall in summer compared to winter. Climatological data related to precipitation, temperature and relative air humidity during the experimental period are presented in Figure 1. The total precipitation volume during the experiment was 412.2 mm, the average air temperature was 25.4 ºC and the average relative humidity was 72.7%.



Source: Weather Station located in the experimental area. Rio Verde, GO, Brazil.

Figure 1. Precipitation (mm), maximum and minimum air temperature (°C) and mean relative humidity (%) during the period of the field experiment carried out with herbicide combinations to control weeds in pre-sowing burndown.

Previous crop in the experimental area was soybean, which was grown in the 2020/2021 season. Before setting up the experiment, soil samples were collected at 0-20 cm depth and analyzed, and the analysis revealed the following physicochemical properties: pH in $CaCl_2$ of 5.0; 4.3 $cmol_c$ dm^{-3} of H^+ + Al^{+3}; 1.7 $cmol_c$ dm^{-3} of Ca^{+2}; 0.5 $cmol_c$ dm^{-3} of Mg^{+2}; 0.19 $cmol_c$ dm^{-3} of K^+; 43.0 mg dm^{-3} of P; 24.0 g dm^{-3} of OM; 37.8% of sand; 18.2% of silt; and 44.1% of clay (clayey texture).

In the selection of the experimental area, the criterion adopted was choosing an area with history of high weed infestation, in order to ensure that there was a high density of individuals composing the weed community at the time of application of the treatments. In addition, also in order to ensure that the weed community was well established when the experiment was set up, weekly irrigations were carried out, with a depth of ≈ 20 mm, throughout August and September.

The experimental design was randomized blocks, evaluating eleven treatments and four replicates (Table 1). The commercial products used were: Preciso XK®, Zapp QI®, Nufosate®, Poquer® and DMA 806 BR®, having as active ingredients, respectively, the herbicides glyphosate potassium salt (540 g a.e. L^{-1}), glyphosate potassium salt (500 g a.e. L^{-1}), glyphosate isopropylamine salt (360 g a.e. L^{-1}), clethodim (240 g a.i. L^{-1}) and 2,4-D amine (806 g a.e. L^{-1}). For all treatments, Agris® mineral oil (0.5% V/V) was added to the application solution. The experimental units were 5 m long and 4 m wide, with a total area of 20 m^2. For the border, 0.5 m of each end of the experimental units was disregarded in the evaluations, with a total usable area of 12 m^2.

Table 1. Treatments and respective doses used in the experiment conducted with glyphosate-based formulations applied alone and in combinations to control weeds in pre-sowing burndown.

Treatments	Dose (g a.e. or a.i. ha^{-1})
1. Glyphosate potassium salt (540)	1080
2. Glyphosate potassium salt (540)	1620
3. Glyphosate potassium salt (540) + clethodim	1080 + 108
4. Glyphosate potassium salt (540) + 2,4-D amine	1080 + 536
5. Glyphosate potassium salt (500)	1080
6. Glyphosate potassium salt (500) + clethodim	1080 + 108
7. Glyphosate potassium salt (500) + 2,4-D amine	1080 + 536
8. Glyphosate isopropylamine salt (360)	1080
9. Glyphosate isopropylamine salt (360) + clethodim	1080 + 108
10. Glyphosate isopropylamine salt (360) + 2,4-D amine	1080 + 536
11. Control without herbicide	-

Concentrations: glyphosate potassium salt (540 g a.e. L^{-1} or 662 g a.i. L^{-1}); glyphosate potassium salt (500 g a.e. L^{-1} or 620 g a.i. L^{-1}); glyphosate isopropylamine salt (360 g a.e. L^{-1} or 480 g a.i. L^{-1}); 2,4-D amine (670 g a.e. L^{-1} or 806 g a.i. L^{-1}).

Treatments were applied on October 08, 2021 (09:30 to 10:20 a.m.), in post-emergence of weeds in the pre-sowing burndown operation. At the time of application, the soil was moist, air temperature was 25 °C, relative air humidity was 76%, the sky had few clouds (10.0% cloudiness) and there were winds of 1.5 km h^{-1}. At the time of application of the treatments, the species that had the highest occurrence in the experimental area were: *Brachiaria brizantha* (palisade grass), *Digitaria insularis* (sourgrass), *Amaranthus hybridus* (smooth pigweed) and *Conyza* spp. (horseweed) with average densities of 15, 4, 11 and 8 plants per m^2, respectively. It is worth pointing out that all the plants mentioned above were in advanced stages of development (flowering).

All treatment applications were performed using a CO_2 -based constant-pressure backpack sprayer, equipped with a bar with six XR-110.02 fan-type nozzles, application range of 3 m, under pressure of 2.0 kgf cm^{-2}. These application conditions promoted the equivalent to 150 L ha^{-1} of solution.

The variables evaluated were percentage of weed control and percentage of desiccation. For the control evaluations, weeds present in the control treatment without herbicide were used as reference. Percentage of weed control was evaluated at 3, 7, 14 and 28 days after herbicide application (DAA), using a visual scale, 0.0-100.0%, where 0.0% means absence of symptoms and 100.0% means total death of plants (SBCPD, 1995).

In addition, the percentage of weed desiccation was evaluated at 28 DAA. For this evaluation, a 0.25 m^2 metal square with a network of strings spaced every 0.05 m was thrown in the plot, and the areas of desiccated or non-desiccated weeds within the spaces between the strings was used to determine the percentage of desiccation. In this evaluation, two random samplings were performed per experimental unit, using a methodology adapted from the study conducted by Sodré Filho et al. (2004).

Data analysis was performed using SISVAR software (FERREIRA, 2019). For statistical analysis, the data were subjected to analysis of variance by the F test and, when a significant effect was found, the means were compared by the Scott-Knott test, at 5% probability level. Additionally, the comparison of means was performed with contrasts, using the percentages of weed control in the evaluations performed at 3, 7, 14, and 28 DAA in this analysis. Statistical comparison of contrasts was carried out using the Scheffé test, at 5% probability level, considering:

$\hat{C}1$ = glyphosate potassium salt (540) alone versus glyphosate potassium salt (540) in combinations (T1 and T2 *versus* T3 and T4).

$\hat{C}2$ = glyphosate potassium salt (540) alone and in combinations versus glyphosate potassium salt (500) alone and in combinations (T1 to T4 *versus* T5 to T7).

$\hat{C}3$ = glyphosate potassium salt (540) alone and in combinations versus glyphosate isopropylamine salt (360) alone and in combinations (T1 to T4 *versus* T8 to T10).

$\hat{C}4$ = glyphosate potassium salt (500) alone and in combinations versus glyphosate isopropylamine salt (360) alone and in combinations (T5 to T7 *versus* T8 to T10).

RESULTS AND DISCUSSION

Table 2 presents the results of the four evaluations of *B. brizantha* control after application of different herbicide treatments in the pre-sowing burndown operation. At 3 DAA, low levels of control of *B. brizantha* plants were observed, with values ranging between 9.50 and 16.25% among the different herbicide treatments evaluated. This result is related to the translocation profile of the herbicides evaluated in the present study, since all the active ingredients (glyphosate potassium or isopropylamine salt, clethodim and 2,4-D amine) of the commercial products tested have systemic action (PETERSON et al., 2016; KNISS et al., 2022).

Herbicides with systemic action, in general, require a longer time to cause a high level of toxicity to plants treated with these molecules, since their active ingredients need to be redistributed inside the plant. Despite the low control performance observed in this first evaluation, it was possible to notice slight differences in the performance of the treatments; glyphosate potassium salt (540) at the highest dose when applied alone and the combinations between glyphosate potassium salt (540 or 500) and clethodim had the highest levels of control of *B. brizantha*.

Table 2. Percentage of *B. brizantha* control after application of herbicides alone and in combinations in the pre-sowing burndown operation.

Treatments	Dose (g a.e. or a.i. ha^{-1})	*B. brizantha* control (DAA)			
		3	7	14	28
1. Glyphosate potassium salt (540)	1080	11.2 b	80.7 b	100.0 a	100.0
2. Glyphosate potassium salt (540)	1620	16.2 a	85.7 a	100.0 a	100.0
3. Glyphosate potassium salt (540) + clethodim	1080 + 108	15.7 a	88.0 a	100.0 a	100.0
4. Glyphosate potassium salt (540) + 2,4-D	1080 + 536	11.2 b	85.0 a	99.5 a	100.0
5. Glyphosate potassium salt (500)	1080	12.5 b	83.5 b	99.5 a	100.0
6. Glyphosate potassium salt (500) + clethodim	1080 + 108	13.7 a	79.2 c	100.0 a	100.0
7. Glyphosate potassium salt (500) + 2,4-D	1080 + 536	12.5 b	82.7 b	99.0 a	100.0
8. Glyphosate isopropylamine salt (360)	1080	9.5 b	74.0 d	95.0 c	100.0
9. Glyphosate isopropylamine salt (360) + clethodim	1080 + 108	10.0 b	76.2 d	97.2 b	100.0
10. Glyphosate isopropylamine salt (360) + 2,4-D	1080 + 536	9.5 b	81.2 b	97.2 b	100.0
11. Control without herbicide	-	0.0 c	0.0 e	0.0 d	0.0
$F_{Calculated}$		16.86*	735.66*	7358.11*	-
CV (%)		19.03	2.48	0.77	-

*Significant at 5% probability level by the F test. Means followed by the same lowercase letter in the column belong to the same group, according to the Scott-Knott grouping criterion, at 5% probability level.

In the evaluation performed at 7 DAA, a greater control of *B. brizantha* was imposed by the different herbicide treatments, with an overall average of ≈82.0%. On this occasion, all treatments containing glyphosate potassium salt (540), regardless of the dose or whether it was applied alone or in combination, in addition to glyphosate potassium salt (500) applied alone and glyphosate potassium salt (500) and glyphosate isopropylamine salt (360) in combination with 2,4-D amine, were the only ones to impose levels of control of *B. brizantha* above the standard considered satisfactory (≥80.0%). However, it should be noted that, statistically, there was superiority in terms of performance for controlling this weed when glyphosate potassium salt (540) was applied at the highest dose (1620 g a.e. ha^{-1}), in addition to the use of this herbicide in combinations with clethodim or 2,4-D amine.

As a practical example of the aforementioned results, when seeking greater speed of control (desiccation) in areas with predominant infestation of *B. brizantha* in the weed community, the producer can opt for applying higher doses of glyphosate potassium salt (540) or associating this herbicide with clethodim or 2,4-D amine, obtaining the same final performance. Despite that, thinking about the adoption of management strategies to prevent the selection of resistant weed biotypes, it is always wise to use combinations between active ingredients with different mechanisms of action, with also the benefit of broadening the spectrum of control of the weed community (KNISS et al., 2022).

Also regarding the evaluation performed at 7 DAA, it is worth highlighting the slight superiority (≈ 8.0%) in terms of control performance on *B. brizantha* of products based on glyphosate potassium salt, to the detriment of those based on glyphosate isopropylamine salt. Superior performance of products based on glyphosate potassium salt compared to those composed of isopropylamine salt has already been reported in the literature, including for species of the same family as *B. brizantha*, such as *B. decumbens* and *D. horizontalis* (JAKELAITIS et al., 2001; WERLANG et al., 2003).

At 14 DAA, all treatments showed high efficacy in the control of *B. brizantha*, with levels ≥ 95.0%, regardless of the dose used or whether the herbicides were applied alone or in combinations. Despite that, in this evaluation, a slightly higher performance was again observed in the treatments with products based on glyphosate potassium salt compared to those that received application of glyphosate isopropylamine salt. In the final control evaluation (28 DAA), no further differences were observed in terms of performance of the treatments on *B. brizantha*, since all of them were able to cause total death of this weed species.

The results for the evaluations of control of *D. insularis* subjected to herbicide application in the pre-sowing burndown operation are presented in Table 3. Traditionally, *D. insularis* has always been a weed species often found in pastures, coffee plantations, orchards and ruderal areas, such as roadsides and vacant lots, where with the advent of NTS this species began to grow in terms of importance as a weed in Brazilian agriculture, due to its characteristics of aggressiveness (MACHADO et al., 2008; GEMELLI et al., 2012). In the first control evaluation, performed at 3 DAA, no symptoms of toxicity caused by the application of herbicides were observed, and all *D. insularis* plants were similar in the experimental area. It is worth noting that the *D. insularis* population present in the experimental area has resistance to glyphosate (OVEJERO et al., 2017), which explains the behavior observed in terms of insensitivity of this weed to treatments composed of commercial products containing this herbicide molecule in their composition.

At 7 DAA, higher levels of control of *D. insularis* were observed in plants that received application of the combination between glyphosate-based products and clethodim, ranging from 32.5 to 42.5%. Although none of the three treatments mentioned above showed efficacy against *D. insularis* on this occasion, it was observed that the use of products based on glyphosate potassium salt promoted a slight improvement in the control performance of clethodim on this weed. As the main strategy for chemical control in post-emergence of glyphosate-resistant *D. insularis*, producers have adopted herbicides whose mechanism of action is based on the inhibition of the ACCase enzyme (popularly known as graminicides), being fundamental to add glyphosate to the application solution to increase the effectiveness of these herbicide combinations (GEMELLI et al., 2013).

Table 3. Percentage of *D. insularis* control after application of herbicides alone and in combinations in the pre-sowing burndown operation.

Treatments	Dose (g a.e. or a.i. ha^{-1})	*D. insularis* control (DAA)			
		3	7	14	28
1. Glyphosate potassium salt (540)	1080	0.0	2.5 e	2.5 b	0.0 c
2. Glyphosate potassium salt (540)	1620	0.0	8.7 e	3.7 b	0.0 c
3. Glyphosate potassium salt (540) + clethodim	1080 + 108	0.0	42.5 a	76.2 a	68.7 a
4. Glyphosate potassium salt (540) + 2,4-D	1080 + 536	0.0	18.7 c	5.0 b	0.0 c
5. Glyphosate potassium salt (500)	1080	0.0	7.5 e	3.7 b	0.0 c
6. Glyphosate potassium salt (500) + clethodim	1080 + 108	0.0	38.7 a	73.7 a	68.7 a
7. Glyphosate potassium salt (500) + 2,4-D	1080 + 536	0.0	5.0 e	2.5 b	0.0 c
8. Glyphosate isopropylamine salt (360)	1080	0.0	3.7 e	0.0 b	0.0 c
9. Glyphosate isopropylamine salt (360) + clethodim	1080 + 108	0.0	32.5 b	71.2 a	66.2 b
10. Glyphosate isopropylamine salt (360) + 2,4-D	1080 + 536	0.0	11.2 d	2.5 b	0.0 c
11. Control without herbicide	-	0.0	0.0 e	0.0 b	0.0 c
$F_{Calculated}$		-	62.62*	408.80*	2416.36*
CV (%)		-	24.91	15.03	6.97

*Significant at 5% probability level by the F test. Means followed by the same lowercase letter in the column belong to the same group, according to the Scott-Knott grouping criterion, at 5% probability level.

In the evaluation performed at 14 DAA, the peak of action (> percentages of control) was observed for treatments containing clethodim in combination with glyphosate-based products with regard to post-emergence control of *D. insularis*. After this evaluation, there was a trend of reduction in control levels, resulting from the regrowth of *D. insularis* plants treated with herbicides. In practical terms, this indicates that a single application of the combination between products based on glyphosate and clethodim is not sufficient for controlling *D. insularis*, requiring the adoption of new sequential applications with these combinations or use of herbicides with contact action (e.g. diquat or glufosinate) (GEMELLI et al., 2012).

In the evaluation at 28 DAA, the best performance of *D. insularis* control was observed in the treatments with application of glyphosate potassium salt (540 or 500) + clethodim, followed by the combination of glyphosate isopropylamine salt (360) + clethodim. Barroso et al. (2014), in a study conducted to evaluate the performance of products based on different glyphosate salts in applications associated with ACCase inhibitors in the control of *D. insularis*, found that the formulations containing glyphosate ammonium or potassium salt promoted improvements in the effectiveness of graminicides on this weed.

For *A. hybridus*, at 3 DAA, no differences in the control were observed between the treatments with herbicide application and the control treatment, with levels below 5.5% (Table 4). At 7 DAA, there was a marked increase in the control imposed by herbicide treatments on the species, especially glyphosate potassium salt (540) applied at the highest dose and the combination between glyphosate potassium salt (540) and 2,4-D amine, which were the only treatments to show efficacy in the control of *A. hybridus* on this occasion.

Table 4. Percentage of *A. hybridus* control after application of herbicides alone and in combinations in the pre-sowing burndown operation.

Treatments	Dose (g a.e. or a.i. ha^{-1})	*A. hybridus* control (DAA)			
		3	7	14	28
1. Glyphosate potassium salt (540)	1080	1.2 a	77.0 b	86.2 b	87.5 b
2. Glyphosate potassium salt (540)	1620	2.5 a	80.0 a	92.5 a	93.2 a
3. Glyphosate potassium salt (540) + clethodim	1080 + 108	1.2 a	72.5 c	80.0 c	85.0 b
4. Glyphosate potassium salt (540) + 2,4-D	1080 + 536	5.5 a	82.7 a	88.7 b	92.5 a
5. Glyphosate potassium salt (500)	1080	1.2 a	72.5 c	82.5 c	85.0 b
6. Glyphosate potassium salt (500) + clethodim	1080 + 108	1.2 a	71.2 c	83.7 c	83.7 b
7. Glyphosate potassium salt (500) + 2,4-D	1080 + 536	2.5 a	71.2 c	81.2 c	85.7 a
8. Glyphosate isopropylamine salt (360)	1080	1.2 a	71.2 c	80.7 c	83.7 b
9. Glyphosate isopropylamine salt (360) + clethodim	1080 + 108	1.2 a	60.0 d	75.7 d	82.5 b
10. Glyphosate isopropylamine salt (360) + 2,4-D	1080 + 536	2.5 a	74.5 c	81.2 c	86.2 b
11. Control without herbicide	-	0.0 a	0.0 e	0.0 e	0.0
$F_{Calculated}$		1.39^{ns}	293.96*	385.92*	421.32*
CV (%)		28.84	4.00	3.43	3.26

*Significant at 5% probability level by the F test. Means followed by the same lowercase letter in the column belong to the same group, according to the Scott-Knott grouping criterion, at 5% probability level.

At 14 DAA, except for the combination of glyphosate isopropylamine salt (360) + clethodim, all other treatments showed efficacy in the post-emergence control of *A. hybridus*. Despite the efficacy of the treatments on this weed species, on this occasion, differences in performance were observed, with higher levels of control of *A. hybridus* obtained with the herbicides glyphosate potassium salt (540) (1620 g a.e. ha^{-1}) alone, followed by glyphosate potassium salt (540) (1080 g a.e. ha^{-1}) alone and the combination of glyphosate potassium salt (540) + 2,4-D amine.

In the last evaluation (28 DAA), all treatments showed efficacy in the post-emergence control of *A. hybridus*, especially glyphosate potassium salt (540) (1620 g a.e. ha^{-1}) applied alone, in addition to the combinations of glyphosate potassium salt (540 or 500) + 2,4-D amine. It is worth pointing out that, for *A. hybridus*, biotypes with resistance to glyphosate have already been identified in the southern region of Brazil (RESENDE et al., 2022), so it is essential to adopt practices aimed at preventing the selection of new resistant biotypes in other production environments (geographic regions), as well as using these management practices for controlling resistant *A. hybridus* populations that are already established.

In this context, the use of combinations between glyphosate and auxin-mimicking herbicides (e.g., 2,4-D amine) may constitute an interesting alternative to be implemented at the time of pre-sowing burndown, since this combination between herbicides has already had its efficacy proven for another species of the same genus (*Amaranthus palmeri*) with resistance to glyphosate (GONÇALVES NETTO et al., 2019; BRAZ; TAKANO, 2022). In addition, the results found in the present study prove the existence of this possible synergistic effect for the combinations between glyphosate potassium salt and the herbicide 2,4-D amine in the control of *A. hybridus*, since there were increments in the levels of weed control when these combinations were used, compared with the values found when the glyphosate-based products were applied alone.

As observed for *D. insularis*, the *Conyza* spp. population present in the experimental area also has resistance to the herbicide glyphosate (MENDES et al., 2021), which explains the insensitivity of this weed to single post-emergence applications of commercial products formulated with this active ingredient. Thus, at 3 DAA, the levels of control imposed by the treatments were very low (≤6.5%), since *Conyza* spp. plants showed few symptoms of injuries resulting from the toxic action of the herbicides (Table 5). Despite the very low levels of control of *Conyza* spp. observed in this initial evaluation, treatments containing the combination between products based on glyphosate and 2,4-D amine showed slightly superior phytotoxic action compared to the others, with the highest percentages of control of this weed obtained with application of glyphosate potassium salt (540) + 2,4-D amine.

Table 5. Percentage of *Conyza* spp. control after application of herbicides alone and in combinations in the pre-sowing burndown operation.

Treatments	Dose (g a.e. or a.i. ha^{-1})	*Conyza* spp. control (DAA)			
		3	7	14	28
1. Glyphosate potassium salt (540)	1080	0.0 c	0.0 d	0.0 c	0.0 c
2. Glyphosate potassium salt (540)	1620	1.2 c	2.5 c	0.0 c	0.0 c
3. Glyphosate potassium salt (540) + clethodim	1080 + 108	0.0 c	3.7 c	0.0 c	0.0 c
4. Glyphosate potassium salt (540) + 2,4-D	1080 + 536	6.5 a	65.0 a	80.0 a	81.2 a
5. Glyphosate potassium salt (500)	1080	0.0 c	3.7 c	0.0 c	0.0 c
6. Glyphosate potassium salt (500) + clethodim	1080 + 108	0.0 c	0.0 d	0.0 c	0.0 c
7. Glyphosate potassium salt (500) + 2,4-D	1080 + 536	3.7 b	66.5 a	80.0 a	80.7 a
8. Glyphosate isopropylamine salt (360)	1080	0.0 c	0.0 d	0.0 c	0.0 c
9. Glyphosate isopropylamine salt (360) + clethodim	1080 + 108	0.0 c	7.5 b	0.0 c	0.0 c
10. Glyphosate isopropylamine salt (360) + 2,4-D	1080 + 536	2.5 b	62.5 a	76.2 b	79.5 b
11. Control without herbicide	-	0.0 c	0.0 d	0.0 c	0.0 c
$F_{Calculated}$		8.95*	494.96*	2803.58*	7334.09*
CV (%)		22.99	13.69	6.47	4.00

*Significant at 5% probability level by the F test. Means followed by the same lowercase letter in the column belong to the same group, according to the Scott-Knott grouping criterion, at 5% probability level.

At 7 DAA, the highest percentages of control of *Conyza* spp. were again observed with the application of combinations containing glyphosate + 2,4-D amine, regardless of the salt or the concentration of acid equivalent of the product used based on the EPSPs inhibitor. Although on this occasion none of the treatments reached the satisfactory level of weed control established for herbicide registration, percentages ranging from 62.5 to 66.5% were observed. Studies published in the literature indicate that, for *Conyza* spp. plants taller than 20 cm, the peak of control imposed by the combination between glyphosate and 2,4-D amine occurs from two weeks after application (OLIVEIRA NETO et al., 2010; OLIVEIRA NETO et al., 2013), given the behavior that these herbicides show inside plants after their absorption and translocation (systemic).

In the evaluations performed at 14 and 28 DAA, the good performance of the combination of products based on glyphosate and 2,4-D amine in the control of *Conyza* spp. was evident. Combinations between these active ingredients have already been pointed out in the literature as synergistic for a number of weed species that are difficult to control, including glyphosate-resistant *Conyza* spp. (TAKANO et al., 2013). It is worth pointing out that, in these evaluations, despite the good performance observed in treatments with combination between glyphosate and 2,4-D amine, *Conyza* spp. control levels above 80.0% were obtained only in those with glyphosate potassium salt (540) + 2,4-D amine or glyphosate potassium salt (500) + 2,4-D amine.

Table 6 presents the results of the overall weed control evaluations, as well as the percentage of desiccation at 28 DAA, as a function of the application of different herbicide treatments in the pre-sowing burndown operation. At 3 DAA, the levels of overall weed control, which are related to the effect of the treatments on all the flora that made up the weed community at the time of application, ranged from 9.0 to 13.0%. Despite the low levels of control, which are expected, given the short time interval between the date of application and the moment that the present evaluation was performed, a slightly higher performance was observed in the experimental units that received application of glyphosate potassium salt (540) (1620 g a.e. ha^{-1}) alone and the combinations of glyphosate potassium salt (540) + 2,4-D amine and glyphosate potassium salt (500) + 2,4-D amine.

In the second evaluation, performed at 7 DAA, there was a marked improvement in the overall control of weeds present in the experimental area due to the post-emergence application of herbicides, with an average percentage of 75.0% among the evaluated treatments. On this occasion, the best performances were observed with the application of glyphosate potassium salt (540) (1620 g a.e. ha^{-1}) alone, glyphosate potassium salt (540) + clethodim or 2,4-D amine and glyphosate isopropylamine salt (360) + 2,4-D amine, with percentages of control above the level considered satisfactory only in the treatments with application of glyphosate potassium salt (540) (at the highest dose) and glyphosate potassium salt (540) + 2,4-D amine. From the evaluation performed at 14 DAA, no more differences were found between the treatments regarding the overall control of weeds, with high efficacy of these treatments in the control of the weed community.

Table 6. Percentage of overall control and desiccation of weeds after application of herbicides alone and in combinations in the pre-sowing burndown operation.

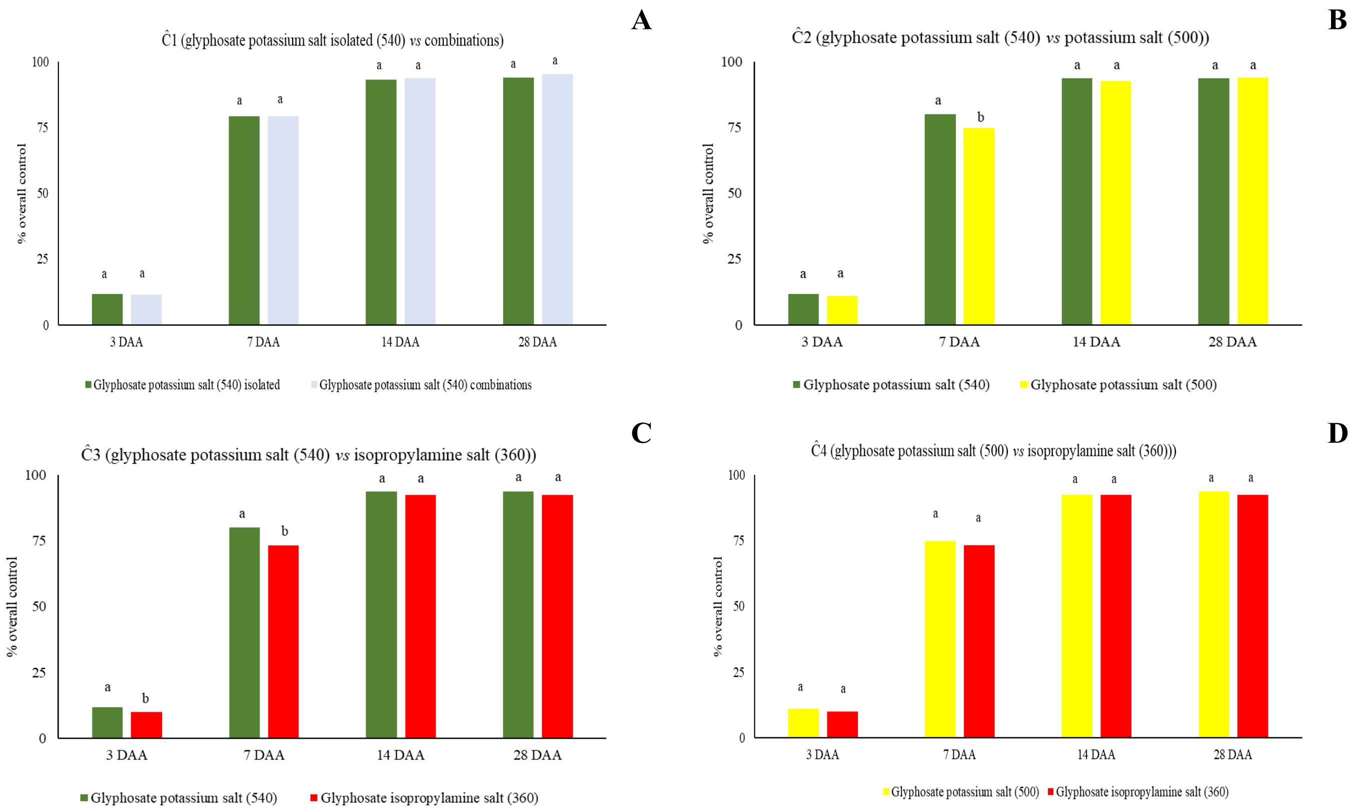
Treatments	Dose (g a.e. or a.i. ha^{-1})	Overall control (DAA)				Desiccation
		3	7	14	28	
1. Glyphosate potassium salt (540)	1080	10.5 b	75.0 b	92.5 a	94.0 a	92.5 b
2. Glyphosate potassium salt (540)	1620	13.0 a	83.7 a	93.7 a	93.7 a	93.7 a
3. Glyphosate potassium salt (540) + clethodim	1080 + 108	11.0 b	79.5 a	90.0 a	93.5 a	91.2 b
4. Glyphosate potassium salt (540) + 2,4-D	1080 + 536	12.2 a	81.5 a	97.2 a	97.2 a	95.0 a
5. Glyphosate potassium salt (500)	1080	10.0 b	73.2 b	93.7 a	93.7 a	93.7 a
6. Glyphosate potassium salt (500) + clethodim	1080 + 108	10.5 b	75.0 b	91.2 a	92.7 a	91.2 b
7. Glyphosate potassium salt (500) + 2,4-D	1080 + 536	12.5 a	76.2 b	92.5 a	95.0 a	95.0 a
8. Glyphosate isopropylamine salt (360)	1080	9.0 b	70.7 b	92.5 a	92.5 a	92.5 b
9. Glyphosate isopropylamine salt (360) + clethodim	1080 + 108	9.5 b	71.5 b	91.2 a	91.2 a	91.2 b
10. Glyphosate isopropylamine salt (360) + 2,4-D	1080 + 536	11.0 b	77.5 a	93.7 a	93.7 a	93.7 a
11. Control without herbicide	-	0.0 c	0.0 c	0.0 b	0.0 b	0.0 c
$F_{Calculated}$		20.94*	212.68*	359.89*	952.44*	914.67*
CV (%)		15.49	4.62	3.50	2.15	2.20

*Significant at 5% probability level by the F test. Means followed by the same lowercase letter in the column belong to the same group, according to the Scott-Knott grouping criterion, at 5% probability level.

For the evaluation of percentage of desiccation, performed at 28 DAA, all treatments were able to impose levels above 91.25%, which correlates with the high level of control (desiccation) of the weeds present in the experimental units on this occasion. To ensure a good quality of sowing, it is essential that the vegetation present in the area is virtually dead prior to planting the crop, because this will reduce the risks of negative effects on machinery performance in the sowing process, besides attenuating the losses caused by the initial interference of the weed community in the crop establishment phase (CONSTANTIN et al., 2009).

To better understand the performance of glyphosate potassium salt (540) in comparison with the other herbicides evaluated, four contrasts were made between treatment groups for the variables related to the percentage of overall weed control, and the results are presented in Figure 2. Comparisons of the effects between treatments with single application of glyphosate potassium salt (540) (T1 and T2) and treatments in which this herbicide was combined with clethodim or 2,4-D amine (T3 and T4) showed no differences in the overall weed control performance in any of the evaluations (Figure 2A).

For the contrasts comparing treatments containing glyphosate potassium salt (540) with those composed of the other glyphosate-based products, glyphosate potassium salt (540) showed better performance in the overall weed control at 7 DAA and at 3 and 7 DAA, respectively, compared to glyphosate potassium salt (500) and glyphosate isopropylamine salt (360) (Figures 2B and 2C). In the other overall control evaluations (14 and 28 DAA), the overall weed control performance was similar between treatments containing glyphosate potassium salt (540) and those with glyphosate potassium salt (500) or glyphosate isopropylamine salt (360). Additionally, for the contrast between treatments containing glyphosate potassium salt (500) and those containing glyphosate isopropylamine salt (360), again no differences were observed throughout the overall control evaluations (Figure 2D).



Means followed by distinct letters, for each evaluation period, differ from each other by the Scheffé test, at 5% probability level.

Figure 2. Contrasts for percentage of overall weed control at 3, 7, 14 and 28 DAA of herbicides in the pre-sowing burndown operation.

These results indicate a slight superiority of glyphosate potassium salt (540) with regard to higher speed of weed control, a behavior that is more pronounced when comparing this commercial product with glyphosate isopropylamine salt (360), an effect explained by the differentiation of the salt used in the formulation of glyphosate potassium salt (540). Finally, it is worth pointing out that the glyphosate potassium salt (540) showed overall performance in weed control at least similar to that of the standard glyphosate potassium salt (500), which indicates the excellent performance of this product for weed community management in pre-sowing burndown. In addition, it is worth noting that, for having a higher concentration of the active ingredient in its commercial formulation, the glyphosate potassium salt (540) allows the application of lower doses per hectare, bringing the logistical benefit of a smaller volume of packaging to be stored on the farm.

CONCLUSIONS

For all weed species evaluated, glyphosate potassium salt (540) shows control performance similar or superior to that observed in the treatments containing glyphosate potassium salt (500) or glyphosate isopropylamine salt (360), which demonstrates that its performance is influenced both by the glyphosate salt used in the composition of the commercial product and by its concentration.

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