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Glyphosate formulations containing different salts in the desiccation of *Urochloa brizantha* "BRS Piatã"

Formulações de glifosato contendo diferentes sais na dessecação de Urochloa brizantha "BRS Piatã"

José Flavio Firmani[1]*; Gustavo Henrique Gasque[2]; Alexandre Chiang[2]; Ana Kely Meira Volpato[2]; João Pedro Mariano Ogido[3]; Rubia Fernanda Bovo[3]; Halley Caixeta Oliveira[4]; Giliardi Dalazen[5]

Highlights

Glyphosate salt affects the speed of desiccation of Piatã grass.
This study presents relevant considerations on Urochloa desiccation with glyphosate.
Plant development conditions affect the quality of desiccation.

Abstract

Glyphosate, the most widely used herbicide in the world, is marketed in different formulations and salts, which can alter its performance in the field. The objective of this study was to evaluate the efficiency of five different glyphosate formulations in the desiccation of *Urochloa brizantha* BRS "Piatã". Two experiments were conducted in two field locations: Alvorada do Sul-PR (Experiment 1) and Londrina-PR (Experiment 2). Five glyphosate formulations (isopropylamine salt, IPA; diammonium salt, Di-NH_4^+; potassium salt, K^+; NH_4^+ salt; and IPA salt + K^+) were tested at two rates: 900 and 1,800 g a.e. ha^{-1}. In Experiment 1, the K^+ salt formulation resulted in a faster effect than the others. The NH_4^+ and IPA formulations were slower, even 28 days after application. In Experiment 2, there was no difference between the formulations, except for the effect of the application rate. In general, the experiments demonstrated that the 1,800 g a.e. ha^{-1} rate was more effective in plant control than the 900 g a.e. ha^{-1} rate, highlighting the importance of using the correct rate for desiccation, in addition to selecting the most appropriate formulation for each environment. The K^+ salt formulation accelerated the mortality kinetics of *Urochloa* grass.

Key words: Chemical control; Herbicides; No-tillage; Pre-planting; Rates.

[1] Doctoral Student of the Post Graduate Program in Agronomy, Universidade Estadual de Londrina, UEL, Londrina, PR, Brazil. E-mail: jose.flavio.firmani@uel.br
[2] Agronomy Undergraduate Students, UEL, Londrina, PR, Brazil. E-mail: gustavo.henrique3@uel.br; alexandre.chiang@uel.br; ana.kely.meira@uel.br
[3] Master of Science in Agronomy, UEL, Londrina, PR, Brazil. E-mail: jpm-27@outlook.com; rubiafbovo@gmail.com
[4] Prof. Dr., UEL, Londrina, PR, Brazil. E-mail: halley@uel.br
[5] Prof. Dr., Universidade Estadual de Ponta Grossa, UEPG, Ponta Grossa, PR, Brazil. E-mail: giliardidalazen@gmail.com
* Author for correspondence

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Resumo

O glifosato, herbicida mais utilizado no mundo, é comercializado sob diferentes formulações e sais, que podem alterar o desempenho do herbicida no campo. O objetivo do presente estudo foi verificar a eficiência de cinco diferentes formulações de glifosato na dessecação de *Urochloa brizantha* BRS "Piatã". Dois experimentos foram conduzidos em dois locais a campo, Alvorada do Sul-PR (Experimento 1) e Londrina-PR (Experimento 2). Cinco formulações de glifosato (sal de isoprapilamina-IPA, sal de di-amônio – Di-NH_4^+, sal de potássio – K^+, sal de NH_4^+, sal de IPA + K^+) foram testadas em duas doses, 900 e 1,800 g e.a. ha^{-1}. No experimento 1, a formulação de sal de K^+ resultou em efeito mais rápido que as demais. As formulações NH_4^+ e IPA se mostraram mais lentas, aos 28 dias após a aplicação dos tratamentos. No experimento 2, não houve diferença entre as formulações, somente para as doses. De modo geral, os experimentos demonstraram que a dose de 1,800 g e.a. ha^{-1} foi superior no controle das plantas do que a dose de 900 g e.a. ha^{-1}, o que ressalta a importância do uso da dose correta para dessecação, além da escolha da formulação mais adequada para cada ambiente, visto que a formulação de sal de K+ acelerou a cinética de mortalidade para o capim Urochloa.
Palavras-chave: Controle químico; Doses; Herbicidas; Plantio-direto; Pré-plantio.

Introduction

The no-till system (NTS) was established based on minimal soil disturbance, permanent ground cover, and crop rotation (Possamai et al., 2022). Crop rotation is essential for a successful NTS, and the choice of species affects how the system responds to the production environment (Balota et al., 2014). Among the available species, the genus *Urochloa* has stood out as an excellent option for NTS management due to its excellent ground cover biomass production (Burin, 2017), including in intercropping systems (Alves et al., 2013).

Proper desiccation is essential to ensure that the crop sown after the cover species develops under good conditions (Santos et al., 2022). Glyphosate, introduced to the market in 1974, is currently the most widely used chemical molecule in agriculture. Its use in *Urochloa* species for pre-planting desiccation is common, as it is a non-selective herbicide with a broad control spectrum, post-emergent and systemic. Its action is based on the inhibition of the enzyme EPSPS (5-enolpyruvylshikimate-3-phosphate synthase), which blocks the synthesis of the amino acids phenylalanine, tyrosine, and tryptophan (Fadin et al., 2018).

The n-octanol/water partition coefficient of glyphosate (Log Kow = −3.4) and its weak acidic nature result in excellent mobility within plants, both acropetally and basipetally (Gao et al., 2023). However, these same properties limit its absorption. The absorption rate depends on the species, development stage, environmental conditions, physiological status of the target plant, and the concentration of the active ingredient in the application medium (Monquero et al., 2004).

The formulation also affects herbicide absorption and translocation (Santos et al., 2007). Glyphosate is sold in salt forms such as isopropylamine, diammonium, monoammonium, potassium, trimethylsulfonium, and sesquisodium salts (Travlos et al., 2017). The glyphosate molecule consists of a carboxylic acid linked to an amine group and a phosphonic group. One of the hydroxyls contains ionizable hydrogen, which can be replaced by different salts, resulting in various formulations and acid equivalent (a.e.) concentrations (Cobb & Reade, 2010; Piasecki, 2024).

The efficiency of these formulations has been studied for some years, but results vary across the literature. In a study with four weed species, Mueller et al. (2006) found no difference in control between formulations containing potassium, isopropylamine, and diammonium salts. Similarly, Cavalieri et al. (2022) found no difference between ammonium and isopropylamine formulations for controlling *Digitaria insularis.* However, they did observe differences in the droplet contact angle on artificial surfaces, a parameter related to target coverage and application technology. Conversely, Jakelaitis et al. (2005) reported that the isopropylamine salt formulation had lower herbicidal activity than ammonium and potassium salts in controlling *U. plantaginea.* In an analysis of data from multiple experiments, Mahoney et al. (2014) found differences between glyphosate formulations when low rates were used across several weed species.

These studies demonstrate a range of outcomes when comparing glyphosate formulations, but studies comparing all individual salt formulations currently available on the Brazilian market are rare. Therefore, the objective was to evaluate the effect of five glyphosate formulations containing different salts at two rates (900 and 1,800 g a.e. ha^{-1}) for the desiccation of *Urochloa brizantha* "BRS Piatã", a species known to be susceptible to glyphosate. The following hypotheses were tested: 1. The type of salt formulation influences herbicide efficacy. 2. Salt formulations with higher concentrations show less interaction with plants due to formulation adjuvants.

Materials and Methods

Location and plant material

Two field experiments were conducted from September to October 2023 and from January to March 2024, respectively, using Urochloa brizantha BRS "Piatã" as the target species.

Experiment 1 was conducted in the municipality of Alvorada do Sul-PR, Brazil, at the Sítio Cerro Alegre farm (22º43'26"S, 51º17'09''W, altitude: 419 m), where the soil is classified as eutroferric red latosol. The species was grown in intercropping with corn. Corn was cultivated from March to August 2024, and Urochloa was sown simultaneously using a third seed box system attached to a precision planter, at a row spacing of 45 cm and a sowing rate of 12 kg ha^{-1}.

The experiment began 40 days after the corn harvest. At the time of treatment application, the plants were approximately 40 cm tall and had a fresh weight of approximately 9,500 kg ha^{-1}. Figure 1 shows the water balance for Alvorada do Sul-PR at the experimental site. Precipitation data (mm) were collected on-site using a rain gauge, while evapotranspiration data (ETP) were kindly provided by Embrapa-Soja (Londrina-PR) and are based on the Thornthwaite & Mather (1955) method, using a soil water storage capacity (WHC) of 75 mm (Silbaldelli et al., 2024).

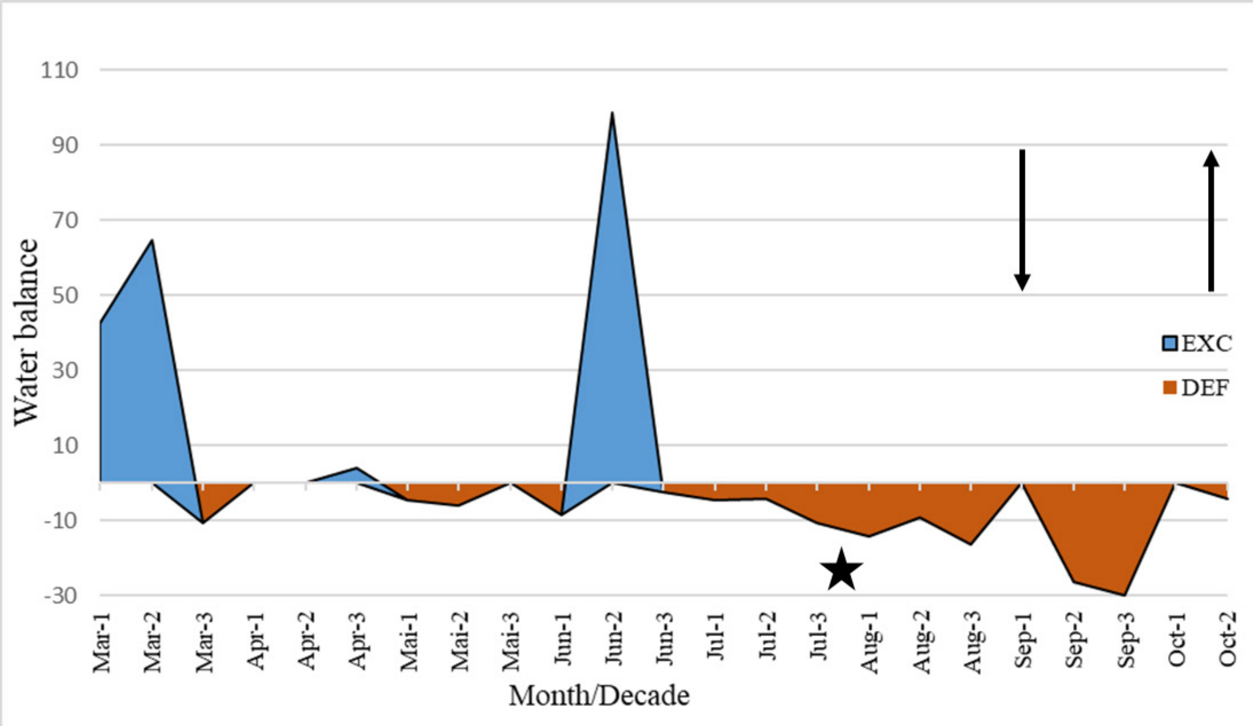

Figure 1. Ten-day water balance of Alvorada do Sul – Paraná. The asterisk (*) indicates the time of corn harvest and the arrows indicate the beginning and end of the experiment. EXC: excess, DEF: deficit.

Experiment 2 was conducted at the School Farm of the State University of Londrina (Fazesc-UEL) (26º20’33”S, 51º12’41”W, altitude: 566 m), in the city of Londrina-PR, Brazil. The target species was planted following conventional soil preparation, in a monoculture system, using a seeder with 19 cm spacing between rows and a seeding rate of 12 kg ha^{-1}.

The field trial was carried out from November 2023 to March 2024, with the application performed in January 2024. To maintain the area, eudicotyledonous weeds were controlled using the herbicide 2,4-D (670 g a.e. ha^{-1}) when the grass had developed three tillers. At the time of application, the plants were approximately 95 cm tall and had a biomass of around 30,000 kg ha^{-1}.

Figure 2 shows the water balance for Londrina. Precipitation data (mm) were kindly provided by IDR-PR (Londrina-PR), collected from a local meteorological station, while evapotranspiration data (ETP) were kindly provided by Embrapa-Soybean (Londrina-PR), based on the Thornthwaite & Mather method (1955), with a water holding capacity of 75 mm (Silbaldelli et al., 2024).

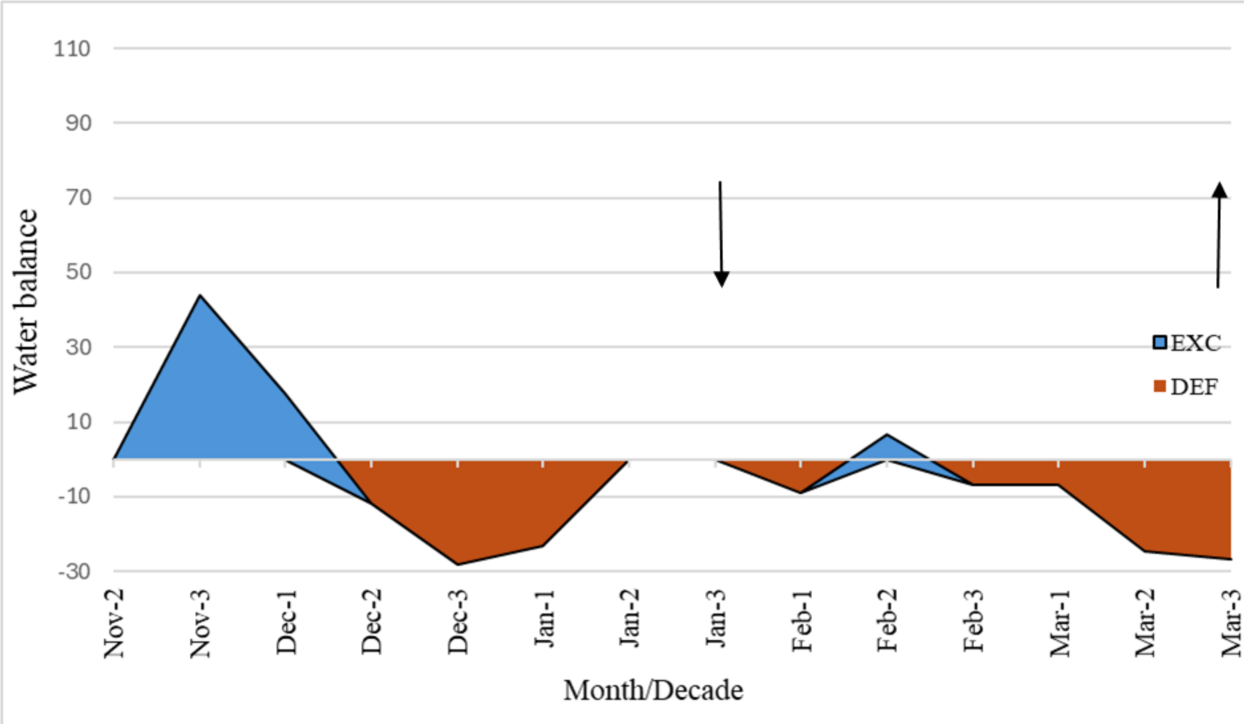

Figure 2. Water balance at the School Farm of the State University of Londrina (Fazesc-UEL). Arrows indicate the beginning and end of the experiment. EXC: excess, DEF: deficit.

Experimental design and application of treatments

The same treatments were applied in both environments, using a randomized block design with four replications. Each experimental plot measured 16 m² (3.2 × 5 m) and was analyzed separately. Treatments were arranged in a 5 × 2 + 1 factorial design, where factor A consisted of five glyphosate formulations: isopropylamine salt (IPA) (NUFOSATE – SUMITOMO CHEMICAL BRASIL INDÚSTRIA QUÍMICA S.A.), diammonium salt (Di-NH_4^+) (Roundup Original® Mais – MONSANTO DO BRASIL LTD.), potassium salt (K+) (Roundup Transorb® R – MONSANTO DO BRASIL LTD.), ammonium salt (NH_4^+) (Roundup WG® – MONSANTO DO BRASIL LTD.), and IPA + K^+ salt (CRUCIAL – SUMITOMO CHEMICAL BRASIL INDÚSTRIA QUÍMICA S.A.). Factor B corresponded to two application rates (900 and 1,800 g a.e. ha^{-1}), in addition to a control treatment.

Treatments were applied using a CO_2-pressurized sprayer coupled to a 3 m spray boom equipped with six ADI 110015 spray nozzles, at an application rate of 110 L ha^{-1}. Weather conditions at the time of application were ideal (relative humidity > 55%, maximum temperature: 28 ºC, wind speed < 10 km h^{-1}), with no dust on the leaves and no rainfall for at least 6 h post-application. In both locations, the water used for application came from the municipal supply system of Londrina-PR.

Evaluations

Seven days after application (DAT), a leaf chlorophyll index analysis was performed using a chlorophyll meter (Brand: atLEAF, Model: CHL BLUE). The analysis was carried out on a fully expanded leaf directly exposed to the treatment, and the device was set to record the average chlorophyll index of the selected leaf. Two samples were collected per plot. At 7, 14, 21, and 28 DAT, visual control assessments were performed using the scale proposed by Frans et al. (1986).

At the end of the experiment, using a 40 × 40 cm sampling frame, fresh weight (FW) of the plant shoots was collected in two samples per experimental unit. Samples were then dried in a forced-air oven at 60 ºC until reaching constant dry weight (DW). The FW and DW values were used to calculate the water content (%H_2O) on an as-is basis, as described by Morais Guimarães and Fernando Stone (2008). All evaluations were conducted within the usable area of each plot, excluding 0.5 m from each end.

Data analysis

The experiments were analyzed separately due to significant differences in experimental sites and conditions. Data were subjected to ANOVA, and all treatments were compared to the control using Dunnett's test. Herbicide treatments were subsequently compared using Tukey's test ($p < 0.05$). Data were transformed as necessary to meet ANOVA assumptions using √X transformation.

Results and Discussion

In the experiment conducted in Alvorada do Sul, in a corn-grass intercropping system, there was no interaction between formulation and rate; only isolated factor effects were observed. No significant differences were found between formulations in the visual evaluation at 7 DAT (Table 1), and all treatments caused greater injury than the control. Similarly, in the chlorophyll index evaluations, only the IPA + K^+ formulation did not differ statistically from the control. There was also no effect of the application rate on these variables. The 14 DAT visual evaluation showed that the K^+ salt and IPA + K^+ formulations resulted in greater injury to the plants.

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Table 1
Percentage of visual control at 7, 14, 21, and 28 days after treatment (DAT) in *Urochloa brizantha* BRS "Piatã" plants subjected to the application of glyphosate salts at two rates (900 and 1,800 g a.e. ha^{-1}), in the experiment carried out in Alvorada do Sul

	Vis. 7 DAT			Vis. 14 DAT		
	%			%		
Treatment	900 g a.e. ha^{-1}	1800 g a.e. ha^{-1}	Mean	900 g a.e. ha^{-1}	1800 g a.e. ha^{-1}	Mean
IPA	*18.7	*23.7	21.2 a	*38.7	*40	39.3 ab
Di-NH_4^+	*21.3	*23.7	22.5 a	*41.2	*43.7	42.4 ab
K^+	*22.5	*21.2	21.9 a	*42.5	*51.2	46.8 a
NH_4^+	*17.5	*21.2	19.4 a	*32.5	*41.2	36.8 b
IPA + K^+	*18.7	*20	19.4 a	*36.2	*38.7	37.4 ab
Mean	19.73 A	21.96 A		38.22	42.96	
Control	0			0		
CV (%)	13			8.14		
	Vis. 21 DAT			Vis. 28 DAT		
	%			%		
Treatment	900 g a.e. ha^{-1}	1800 g a.e. ha^{-1}	Mean	900 g a.e. ha^{-1}	1800 g a.e. ha^{-1}	Mean
IPA	*42.5	*47.5	45.0 b	*45	*53.7	49.4 b
Di-NH_4^+	*46.2	*51.2	48.7 ab	*\50.0	*55	52.5 ab
K^+	*51.2	*61.2	56.2 a	*53.7	*68.7	61.2 a
NH_4^+	*40.0	*47.5	43.8 b	*42.5	*56.2	49.4 b
IPA + K^+	*46.2	*50	48.1 ab	*51.2	*61.2	56.2 ab
Mean	45.22 B	51.48 A		48.48 B	58.96 A	
Control	0			0		
CV (%)	9.16			6.78		

Values are expressed as means (n = 4). Means followed by the same letter do not differ from each other. Lowercase letters compare treatments in the column and uppercase letters compare treatments in the row, according to Tukey's test ($p < 0.05$). * Indicates that there was a difference in relation to the control according to Dunnett's test ($p > 0.05$). CV = coefficient of variation (%). a.e.: acid equivalent. IPA: isopropylamine salt, Di-NH_4^+: diammonium salt, K^+: potassium salt, NH_4^+: ammonium salt, IPA + K^+: isopropylamine salt + potassium salt.

In the evaluations at 21 and 28 DAT, the ammonium salt (NH_4^+) and IPA formulations exhibited lower visual control of the plants (Figure 3). Although the K^+ salt formulation was superior to the others at 28 DAT, it still did not achieve satisfactory control, reaching only 61%. These results are consistent with those observed for the water content, where the K^+ formulation caused the most significant reduction (Table 2). The unsatisfactory control observed, even with the best formulation, can be attributed to environmental conditions from the sowing of the grass in the intercropping system to the time of application.

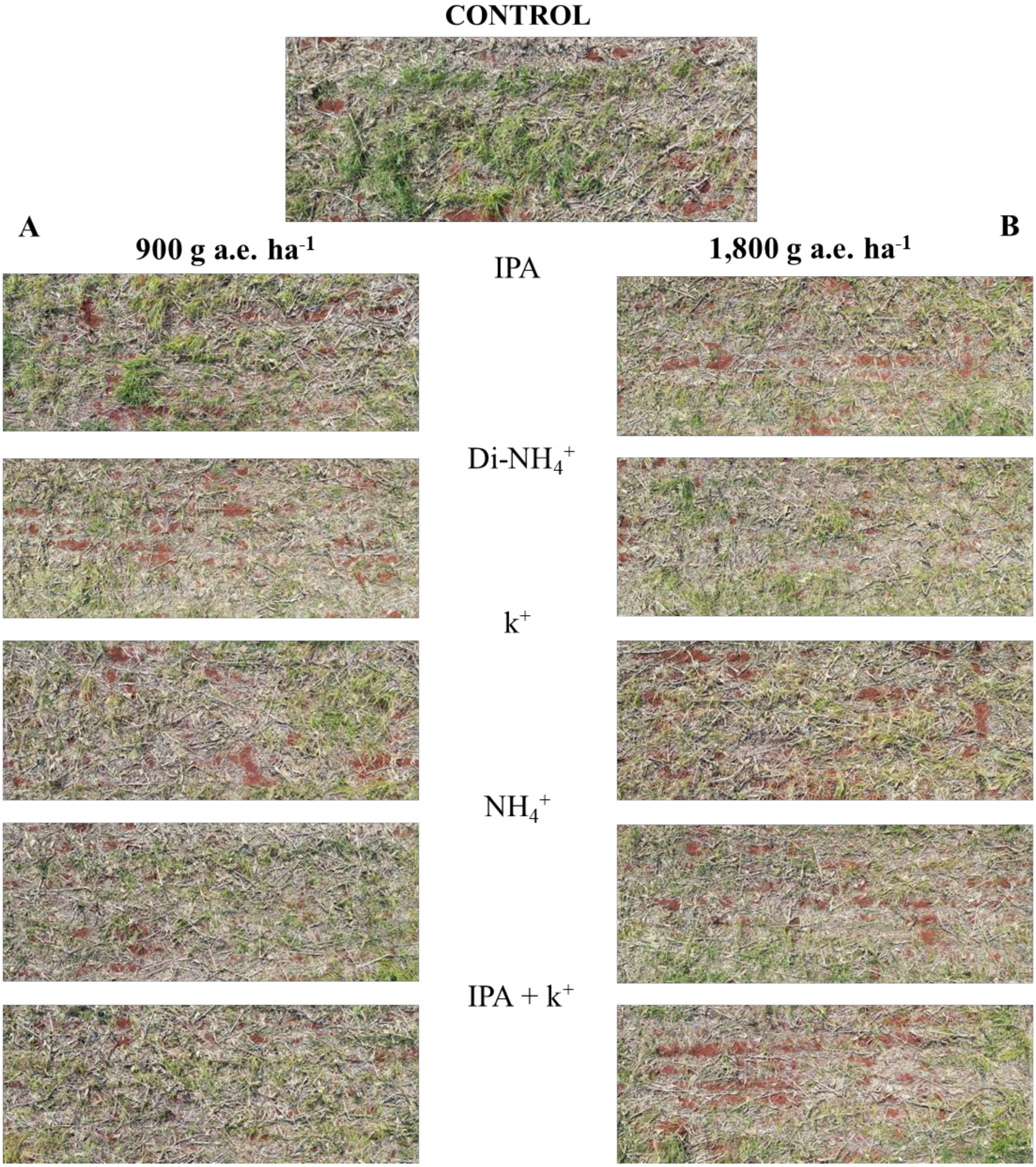

Figure 3. Aerial image of the experimental unit in Alvorada do Sul comparing different formulations of glyphosate salts [isopropylamine (IPA), di-ammonium (Di-NH_4^+), potassium (K^+), ammonium (NH_4^+), and IPA + K^+] 21 days after application of the treatments. A) 900 g a.e. ha^{-1} rate; and B) 1800 g a.e. ha^{-1} rate.

Table 2
Chlorophyll index seven days after application (DAT), shoot fresh and dry weights water content (%H_2O) of *Urochloa brizantha* BRS "Piatã" plants subjected to the application of glyphosate salts at two rates (900 and 1800 g a.e. ha^{-1}), in the experiment carried out in Alvorada do Sul

	Chlorphyll index			Fresh weight (g)		
Treatment	900 g a.e. ha^{-1}	1800 g a.e. ha^{-1}	Mean	900 g a.e. ha^{-1}	1800 g a.e. ha^{-1}	Mean
IPA	*34	*33	33.5 a	196.5	131.3	163.9 a
Di-NH_4^+	*29.7	*32.4	31.1 a	128.4	142.4	135.4 a
K^+	*29.9	*31	30.5 a	125.4	*78.9	102.1 a
NH_4^+	*29.2	*32.1	30.6 a	172.8	*95.8	134.3 a
IPA + K^+	32.7	*35.4	34 a	144.9	165.5	155.2 a
Mean	31 A	32.78 A		153.6 A	122.7 A	
Control	42.31			224.6		
CV (%)	10.9			20.4		
	Dry weight (g-)			**% H_2O (%)**		
Treatment	900 g a.e. ha^{-1}	1800 g a.e. ha^{-1}	Mean	900 g a.e. ha^{-1}	1800 g a.e. ha^{-1}	Mean
IPA	107.1	81.1	94.1 a	*85.3	*56.6	70.9 a
Di-NH_4^+	81.4	92.1	86.8 a	*58	*52	55 ab
K^+	80.8	61.2	71.0 a	*51.2	*27.7	39.4 b
NH_4^+	97.8	69	83.4 a	*76	*36.8	56.4 ab
IPA + K^+	91.8	115.4	103.6 a	*61.4	*39.7	50.5 ab
Mean	91.7 A	83.7 A		66.3 A	42.5 B	
Control	101.2			120.2		
CV (%)	17.4			22.4		

Values are expressed as means (n = 4). Means followed by the same letter do not differ from each other. Lowercase letters compare treatments in the column and uppercase letters compare treatments in the row, according to Tukey's test ($p < 0.05$). * Indicates that there was a difference relative to the control according to Dunnett's test ($p \leq 0.05$). CV = coefficient of variation. a.e.: acid equivalent. IPA: isopropylamine salt, Di-NH_4^+: diammonium salt, K^+: potassium salt, NH_4^+: ammonium salt, IPA + K^+: isopropylamine salt + potassium salt.

Regarding the comparison of application rates, in parameters where significant differences were observed, the 1,800 g a.e. ha^{-1} rate was more effective (Figure 3B). This highlights the importance of the application rate in addition to the formulation for effective grass control. According to Dunnett's test, dry weight did not differ significantly between treatments and the control, and no differences were observed among formulations. For fresh weight, however, only the K^+ and Di-NH_4^+ formulations reduced biomass compared to the control.

In the experiment conducted at Fazesc-UEL, no differences were observed between glyphosate salt formulations for any of the evaluated parameters, nor were there interactions between the rate and formulation factors. However, a significant difference between herbicide rates was found in the visual evaluations at 14, 21, and 28 DAT, with the rate of 1,800 g a.e. ha^{-1} resulting in higher visual injury scores than 900 g a.e. ha^{-1} (Table 3). The water content data (Table 4) supported the visual scale results, as the 900 g a.e. ha^{-1} rate led to higher water content. This indicates slower plant mortality kinetics (Figure 4A), and at 28 DAT, all formulations applied at 1,800 g a.e. ha^{-1} achieved over 85% control (Table 3).

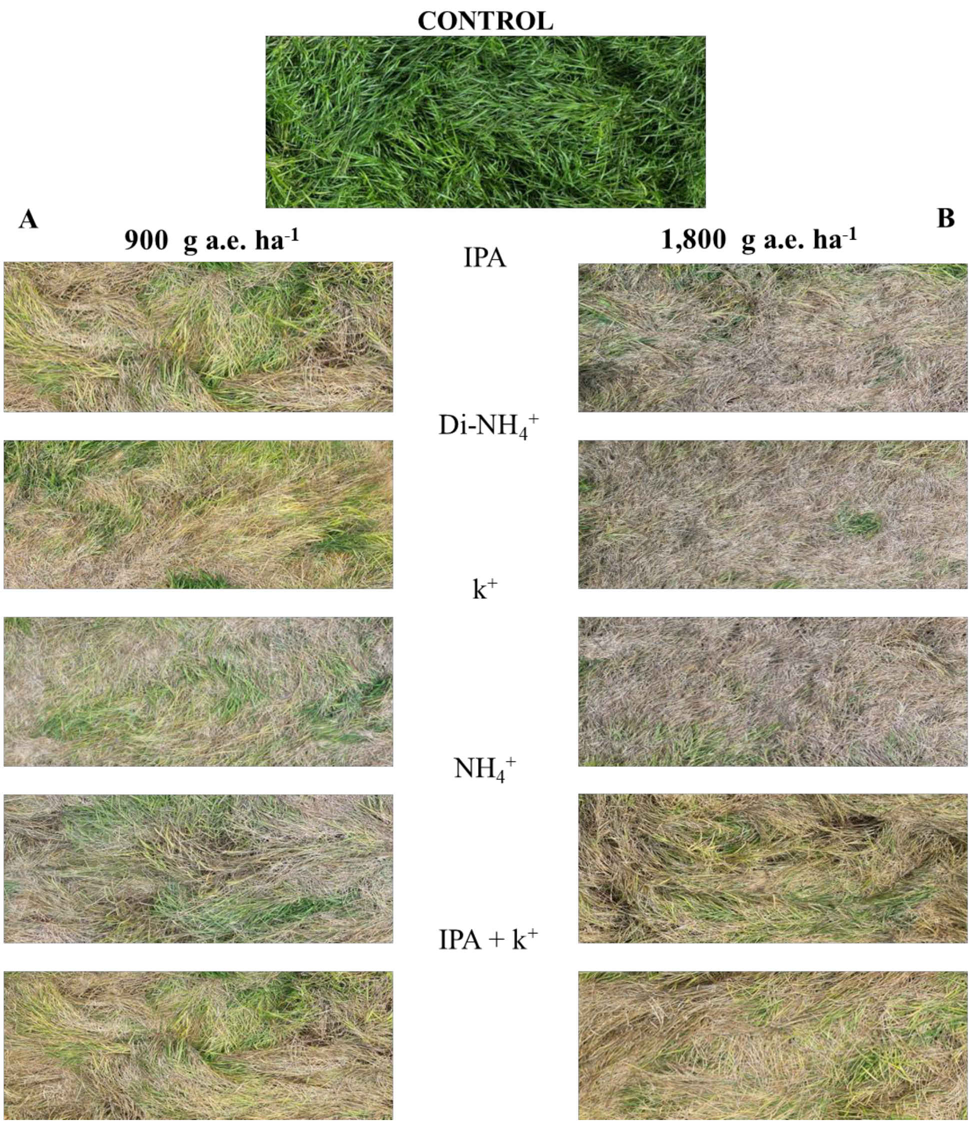

Figure 4. Aerial image of the experimental unit comparing different formulations of glyphosate salts [isopropylamine (IPA), diammonium (Di-NH_4^+), potassium (K^+), ammonium (NH_4^+), and IPA + K^+] 21 days after treatment application. A) 900 g a.e. ha^{-1} rate ;and B) 1800 g a.e. ha^{-1} rate. Experiment 2 (Fazesc-UEL).

Table 3
Percentage of visual control at 7, 14, 21, and 28 days after application (DAT) of glyphosate salts at two rates (900 and 1800 g a.e. ha^{-1}) to *Urochloa brizantha* BRS "Piatã" plants, in the experiment carried out at Fazesc-UEL

	Vis. 7 DAT			Vis. 14 DAT		
	%			%		
Treatment	900 g a.e. ha^{-1}	1800 g a.e. ha^{-1}	Mean	900 g a.e. ha^{-1}	1800 g a.e. ha^{-1}	Mean
IPA	*13.2	*21.2	17.2 a	*30	*40	35 a
Di-NH_4^+	*13.7	*12.5	13.1 a	*30	*40	35 a
K^+	*16.2	*17.5	16.9 a	*30	*37.5	33.8 a
NH_4^+	*18.7	*20.0	19.4 a	*37.5	*38.7	38.1 a
IPA + K^+	*16.2	*18.7	17.5 a	*31.2	*45	38.1 a
Mean	15.6 A	18.0 A		31.7 B	40.2 A	
Control	0			0		
CV (%)	20.6			8.14		
	Vis. 21 DAT			**Vis. 28 DAT**		
	%			%		
Treatment	900 g a.e. ha^{-1}	1800 g a.e. ha^{-1}	Mean	900 g a.e. ha^{-1}	1800 g a.e. ha^{-1}	Mean
IPA	*51.2	*58.7	55.0 a	*73.2	*86.2	79.7 a
Di-NH_4^+	*38.2	*60	49.1 a	*78.3	*90	84.2 a
K^+	*47.5	*60	53.8 a	*72.5	*88.7	80.6 a
NH_4^+	*55.0	*56.2	55.6 a	*78.7	*86.2	82.5 a
IPA + K^+	*48.7	*60	54.4 a	*73.7	*91.2	82.5 a
Mean	48.12 B	58.98 A		75.28 B	88.46 A	
Control	0			0		
CV (%)	7.48			5.13		

Values are expressed as means (n = 4). Means followed by the same letter do not differ from each other. Lowercase letters compare treatments in the column and uppercase letters compare treatments in the row, according to Tukey's test ($p < 0.05$). * Indicates that there was a difference relative to the control according to Dunnett's test ($p \leq 0.05$). CV = coefficient of variation. a.e.: acid equivalent. IPA: isopropylamine salt, Di-NH_4^+: diammonium salt, K^+: potassium salt, NH_4^+: ammonium salt, IPA + K^+: isopropylamine salt + potassium salt.

Table 4

Chlorophyll index seven days after application (DAT), shoot fresh and dry weights, and water content (%H_2O) of *Urochloa Brizantha* BRS "Piatã" plants subjected to the application of glyphosate salts at two rates (900 and 1800 g a.e. ha^{-1}), in the experiment carried out at Fazesc-UEL

	SPAD 7 DAT			Fresh weight (g)		
Treatment	900 g a.e. ha^{-1}	1800 g a.e. ha^{-1}	Mean	900 g a.e. ha^{-1}	1800 g a.e. ha^{-1}	Mean
IPA	36	32.7	34.4 a	*345.2	*309	327.1 a
Di-NH_4^+	36	33.7	34.9 a	*257	*301.5	279.2 a
K^+	*26.2	36.42	31.3 a	*377.5	*310	343.7 a
NH_4^+	*26.1	33.43	29.8 a	*321.5	*326	323.7 a
IPA + K^+	*27.8	*28.1	28.0 a	*359	*304.5	331.7 a
Mean	30.4 A	32.8 A		332 A	310.2 A	
Control	47.1			5704		
CV (%)	14.7			11.7		

	Dry weight (g)			% H_2O (%)		
Treatment	900 g a.e. ha^{-1}	1800 g a.e. ha^{-1}	Mean	900 g a.e. ha^{-1}	1800 g a.e. ha^{-1}	Mean
IPA	*203.9	*224.9	214.4 a	*40.6	*26.7	33.65 a
Di-NH_4^+	*167.2	*204.5	185.9 a	*35	*30.1	32.55 a
K^+	*246.0	*225.2	235.6 a	*34.2	*27.3	30.75 a
NH_4^+	*200.3	*205.2	202.8 a	*35.7	*33.6	34.65 a
IPA + K^+	*235.0	*202.6	218.8 a	*34.1	*32.4	33.25 a
Mean	210.5 A	212.5 A		35.92 A	30.02 B	
Control	2157			64.02		
CV (%)	9.5			12.9		

Values are expressed as means (n = 4). Means followed by the same letter do not differ from each other. Lowercase letters compare treatments in the column and uppercase letters compare treatments in the row, according to Tukey's test ($p < 0.05$). * Indicates that there was a difference relative to the control according to Dunnett's test ($p \leq 0.05$). CV = coefficient of variation. a.e.: acid equivalent. IPA: isopropylamine salt, Di-NH_4^+: diammonium salt, K^+: potassium salt, NH_4^+: ammonium salt, IPA + K^+: isopropylamine salt + potassium salt.

The Dunnett test showed that the K^+, NH_4^+, and IPA + K^+ formulations at the 900 g a.e. ha^{-1} rate differed from the control according to the Chlorophyll Index at 7 DAT, while at the 1,800 g a.e. ha^{-1} rate, only the commercial salt mixture formulation showed a significant difference in this parameter. For all other evaluated parameters (visual control at 7, 14, 21, and 28 DAT; FW; DW; and %H_2O), the herbicide treatments differed significantly from the control, regardless of rate or formulation, indicating that the applications produced the expected effects. Notably, there was an average tenfold reduction in dry weight at the 1,800 g a.e. ha^{-1} rate.

Among the glyphosate formulations tested, the K^+ salt formulation showed earlier onset of visual symptoms compared to the other treatments in the Alvorada do Sul (ALV) experiment (Table 1). Golob et al. (2008) evaluated glyphosate formulations and found that the K^+ salt was more effective than the IPA salt across various broadleaf and grass weed species.

In a study comparing different target species, Oliveira et al. (2015) found that the IPA salt formulation resulted in a smaller wetting area and shorter evaporation time than the K^+ and NH_4^+ salt formulations. The authors also emphasized that, in addition to the active salts, other components in the commercial product, often labeled as inert, play a key role in the stabilization and properties of the commercial product.

Li et al. (2005), in a study using ^{14}C-labeled glyphosate, found no differences in final plant weight among formulations but did observe differences in early evaluation periods (2 and 6 h). For *Abutilon theophrasti,* the IPA formulation was more effective, whereas for *Ipomoea lacunosa,* the Di-NH_4^+ formulation showed better root translocation. These findings reinforce that the dynamics and efficiency of glyphosate formulations depend on the target species. The authors also highlighted that, under field conditions, such differences can lead to variation in control efficacy among formulations, as observed in this study (Table 1).

Although differences were observed among formulations in Experiment 1, the level of control was unsatisfactory. It is hypothesized that water deficit conditions prior to application (Figure 1) were not favorable for plant development. Such environmental stress can trigger anatomical and physiological responses (Silva et al., 2018; Zanatta et al., 2007) that reduce herbicide efficacy (Silva et al., 2018). For instance, Skelton et al. (2016) reported reduced glyphosate absorption and translocation in *Amaranthus tuberculatus* under drought conditions.

Despite the water balance of Experiment 2 indicating that the plants went through periods of water deficit (Figure 2), the water balance in the days preceding the application was neutral, likely resulting in better physiological conditions for herbicide action compared to Experiment 1. Furthermore, at the time of application, the plants in Experiment 2 were larger and had accumulated more biomass, with a greater leaf area, an essential factor for glyphosate absorption.

In the Fazesc-UEL experiment, no differences were observed between formulations in terms of visual control (Table 3). Similarly, Richardson et al. (2003) found no significant difference between IPA and Di-NH_4^+ formulations when controlling *Ambrosia artemisiifolia, Digitaria sanguinalis,* and *Ipomoea species.* For Ligustrum sinense, Harrington and Miller (2005) also reported similar control results between IPA and NH_4^+ salt formulations.

In general, herbicide molecules that are weak acids, such as glyphosate, are modified to improve efficacy, handling, and stability (Travlos et al., 2017). Several factors affect the success of herbicide application. Degradation of the active molecule can begin even within the commercial packaging, although modern formulations ensure chemical stability. From application to reaching and inhibiting the target enzyme, various factors can impair the herbicide's mode of action and reduce its efficacy.

These factors, combined with the characteristics of the target species in this study such as plant size, biomass accumulation, and leaf area corroborate the observed results, confirming that the 1,800 g a.e. ha^{-1} rate was more effective than 900 g a.e. ha^{-1} (Figures 3B and 4B). Higher rates accelerate and increase the kinetics of plant death and enhance herbicide performance (Santos et al., 2022). In addition, other tools can improve glyphosate efficacy, such as the use of adjuvants (Palma-Bautista et al., 2020).

Conclusion

Water stress conditions negatively affected glyphosate efficacy in controlling *U. brizantha,* with clear differences observed among herbicide formulations, particularly the superior performance of the K^+ salt formulation. This study also emphasizes the importance of applying the correct rate for satisfactory control of the species, as the 1,800 g a.e. ha^{-1} rate proved more efficient. These results highlight the importance of understanding the interaction between herbicide formulations, target species, and environmental conditions.

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