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Spraying solo or mixed glyphosate after different ready-mixed solution storage periods

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Abstract

The continuous need to use tank mixtures of herbicides for managing hard-to-control weeds, particularly volunteer soybean in second-crop corn, motivated this study. Therefore, this work was developed in order to evaluate the efficacy of glyphosate (applied solo or in mixtures with 2,4-D or atrazine) following various storage periods of the ready-mixed spray solution. To this end, five greenhouse experiments were carried out from 2015 to 2017, three using an application volume of 240 L ha^{-1} and two with a reduced volume of 120 L ha^{-1}. Treatments followed a factorial design (5×3) + 1, with five storage durations for the ready-mixed spray solution: 1, 24, 48, 96, and 168 hours; three herbicide treatments: glyphosate solo (720 g a.e. ha^{-1}), glyphosate + atrazine (720 + 1,500 g a.e. ha^{-1}), and glyphosate + 2,4-D (720 + 670 g a.e. ha^{-1}); plus, checkplots without application. The bioindicators used were morning glory (*Ipomoea triloba*), sourgrass (*Digitaria insularis*), and volunteer Roundup Ready soybean. Overall, the storage duration of the ready-mixed herbicide solution had no significant impact on herbicide efficacy. Glyphosate solo provided the best control of sourgrass; mixtures of glyphosate with atrazine or 2,4-D most effectively controlled morning glory, and the glyphosate + atrazine and glyphosate + 2,4-D treatments achieved the highest control of volunteer transgenic soybean. Minor indications of antagonism were observed in the mixtures of glyphosate + atrazine and glyphosate + 2,4-D.

Keywords: *Glycine max*. Efficacy. Interaction: Chemical control. Post-emergence.

Introduction

Population growth directly impacts the demand and production of food, prompting producers to exploit the maximum productive potential of their properties and to surpass the productivity levels achieved in previous harvests. However, the loss of a crop's productive potential may be related to the interference of biotic factors, among which is the occurrence of weeds in productive areas. In addition to the direct damages caused by competition and allelopathy, indirect impacts such as the harboring of insects, diseases, interference with harvest, and product quality are also observed (Vasconcelos, Silva, Lima, 2012), especially in crops of great economic importance, such as cotton, corn, and soybean.

In the 2022/23 harvest, corn (*Zea mays* L.) was cultivated on approximately 22.2 million hectares in Brazil, with a productivity of 5,923 kg ha^{-1} and a production of 131,892.6 million tons, of which approximately 102 million tons came from the second crop (CONAB, 2023). According to Nóbrega (2016), in numerous areas of Brazil, the production of this crop is linked to the model of crop succession or no-till farming. Therefore, the second corn crop, or "*safrinha*," is characterized by cultivation following a summer crop, generally after the soybean harvest. This production model enables producers to increase their income, prevents agricultural areas from remaining fallow, optimizes the use of machinery and agricultural implements, and ensures the utilization of nitrogen derived from the biological fixation by soybean.

Accompanying the increase in crop yields, especially for corn, the interference of weeds is recurrent. According to Christoffoleti, Brunharo, and Figueiredo (2015), as corn is sown in succession to soybean, this management may contribute to the selection of resistant weeds, especially to glyphosate, particularly horseweed (*Conyza* spp.) and bittergrass (*Digitaria insularis*).

Moreover, it is important to note that the expansion of agricultural areas with genetically modified, glyphosate-resistant crops, contributes to the development of volunteer plants, such as Roundup Ready (RR) soybean, which grow as weeds in corn fields. Volunteer soybean originates from the germination of grains lost during mechanized harvest (Rizzardi *et al*., 2012) or from broken or lodged plants in the field. It has been shown that volunteer soybean can reduce corn yield by 22% to 40%, depending on the plant density (Adegas, Gazziero, Voll, 2014).

Among the methods for control, chemical control is considered the most widely adopted option in Brazilian agriculture due to its efficient and attractive cost when compared to other methods and shows ease of use. Weed control decisions are strongly influenced by economic factors, so management practices that provide the greatest measurable and short-term economic return tend to be more widely adopted, as is the case with chemical control (Peterson *et al*., 2018).

The combination of certain herbicides that have residual soil activity (atrazine and 2,4-D) with glyphosate not only broadens the spectrum of control but also enables pre-emergence management and reduces early competition stress (Jaremtchuck *et al*., 2008). Lima *et al*. (2011), have evaluated five different mechanisms of action of herbicides to control volunteer plants of different RR soybean cultivars. At 42 days after application (DAA), it was found that the treatment with the mixture of 2,4-D and glyphosate provided 100% elimination of the plants, regardless of the cultivar evaluated. The combination of herbicides is an option for controlling volunteer soybean in corn, and the use of an atrazine and glyphosate association promotes and intensifies the control of broadleaf weeds and volunteer soybean at reduced cost (Trezzi *et al*., 2005).

Considering the interactions and performance of these products in weed management, the period and manner of storing ready-mixed solutions for spraying are topics of study for researchers. Mixing two or more active ingredients or modes of action is an effective strategy to prevent the selection of resistant biotypes and control resistant weeds and species (Abbas *et al*., 2016). However, if underplanned, a tank mixture may lead to various negative aspects, including health and environmental risks, phytotoxic effects on the crop, application issues and control failures due to incompatibilities and interactions between different products, as well as misinformation (Ikeda, 2013; Jesus, 2014).

For example, during rainy periods, there may be a need to store ready-mixed solutions for a certain period of time; thus, the lack of information about the degradation of the stored solution leads some farmers, either out of fear of negative results, to increase the application volume (causing product wastage) or to discard the solution after 24 or 48 hours of storage (Ramos, Durigan, 1998).

In this sense, it is important to understand and assess the impact of using herbicides in mixtures and the factors that may or may not negatively influence their action. Thus, this study was developed to evaluate the efficacy of the herbicide glyphosate (solo, in mixture with 2,4-D, or atrazine) after different storage periods of the ready-mixed solution and at reduced spray volumes.

Material and methods

A total of five independent experiments were carried out from 2015 to 2017, all in the greenhouse of the Federal Institute of Education, Science and Technology of Minas Gerais – Machado Campus (21° 45' S; 45° 55' W; 850 m altitude). The first three experiments (Exp. 1, 2, and 3) were carried out to evaluate the interference of different storage durations of the ready-mixed herbicide solution on the spraying efficacy of glyphosate solo or glyphosate mixed with atrazine or 2,4-D, using a spray volume of 240 L ha^{-1}. The following two experiments (Exp. 4 and 5) had the same treatment protocol but with a reduced spray volume of 120 L ha^{-1}. The experiments were evaluated separately to eliminate any impacts due to the season or time of application. These mixtures were chosen because they are frequently used to eliminate glyphosate-resistant volunteer soybean in the corn grown in succession.

Treatments followed a factorial design (5×3) + 1, with five storage durations for the ready-mixed spray solution: 1, 24, 48, 96, and 168 hours; three herbicide treatments: glyphosate solo (720 g a.e. ha^{-1}), glyphosate + atrazine (720 + 1,500 g a.e. ha^{-1}), and glyphosate + 2,4-D (720 + 670 g a.e. ha^{-1}); plus, checkplots without application. Thus, a total of 16 treatments were employed in a randomized block design with five replications, resulting in 80 plots per experiment.

All mixtures were prepared in a staggered manner so that all applications were performed on the same day. For the herbicide mixture treatments, mineral oil Assist® was added at 0.5% v/v. After each preparation time point, the mixtures were stored in 600 mL PET bottles and kept inside two kraft paper bags to avoid solar radiation during storage—simulating a sprayer tank. Thus, they were stored in a cool and dry place following the pre-established storage durations.

The first experiment (Exp. 1) was developed from March and May 2015. In this experiment, sourgrass (*Digitaria insularis* L. [Fedde]) was employed as a bioindicator plant with a spray volume of 240 L ha^{-1}. Subsequently, two experiments (Exp. 2 and 3) were conducted from September to December 2015 using morning glory (*Ipomoea triloba* L.) and RR soybean (*Glycine max* L. [Merril]) as bioindicator plants, also with a spray volume of 240 L ha^{-1}. Finally, two experiments (Exp. 4 and 5) were conducted from September 2016 and May 2017 using sourgrass and morning glory as bioindicator plants, in this case with a spray volume of 120 L ha^{-1}. The experiments were performed with both monocotyledonous and dicotyledonous species, as well as with transgenic Roundup Ready® (RR) soybean, in order to enable analysis of the effects of the herbicide mixtures and storage on glyphosate, 2,4-D, and atrazine given their different control spectra.

Sourgrass seeds were collected from a non-agricultural area in the municipality of Machado – MG. Subsequently, the seeds were stored in paper bags in a dry place at room temperature until the experiments began. Morning glory seeds were commercially obtained from a company located in the municipality of Cosmópolis – SP, whereas the RR soybean Syn1059 seeds were provided by a company specialized in seed multiplication for large-scale crops (Syngenta).

For the setup of the experiments, the seeds of sourgrass and morning glory were distributed in excess into 2-L plastic trays filled with commercial substrate and vermiculite in a 2:1 ratio. The trays were then allocated in a greenhouse for germination. After seedling emergence, at the stage of two true leaves or cotyledonary leaves, the seedlings were transplanted into 1-L plastic pots filled with a mixture of sieved clayey soil (Table 1), commercial substrate, and vermiculite in a 3:6:1 ratio, and properly fertilized. They were kept in this medium until the completion of the experiment. Regarding density, there was an average of three plants per pot for morning glory and eight plants per pot for sourgrass. The clayey soil was collected from an area adjacent to the greenhouse and maintained under adequate fertility conditions (Table 1).

In the case of soybeans, two seeds were directly sown in the plots at an average depth of 3 cm. Each plot also contained a 1-L pot, utilizing the same mixture of soil, substrate, and vermiculite. After emergence, at the V1 developmental stage, the plots were thinned, leaving only one plant per pot. All pots in all experiments were maintained under automated sprinkler irrigation, ensuring no water or nutritional deficiencies.

All spray applications were performed on plants in a late post-emergence stage—identified as the V3 stage for soybean, the 5-6 leaf stage for morning glory, and the full tillering stage for sourgrass. For this purpose, a precision backpack sprayer, pressurized with CO_2 and fitted with a single-tip boom positioned 0.50 m from the target, model XR TeeJet 110.02 or 110.01, was used. The spray volume was 240 L ha^{-1} for Experiments 1, 2, and 3; and 120 L ha^{-1} for Experiments 4 and 5. The applications were carried out under still air conditions and without any rainfall following the treatments.

Percentage control was evaluated at 14 and 28 days after application (DAA), along with the residual dry mass at 28 DAA. For the control assessments, a score of zero was assigned in the absence of symptoms and 100% for complete plant death (SBCPD, 1995; Table 2). The evaluation team consisted of at least three trained assessors who assigned efficacy ratings in mutual agreement. Plant biomass was obtained by harvesting the remaining plant material in the plots, followed by oven-drying at 70°C for 72 hours. When necessary, the dry mass was converted to percentage values by comparing the biomass obtained from the herbicide treatments with that of the checkplots, which was considered 100%.

Table 1. Physical-chemical characteristics* of the soil employed in the experiments. Machado – MG, 2017

Soil Chemical Analysis											Granulometric Analysis			
pH H_2O	Organic Matter dag kg^{-1}	P mg dm^{-3}	K mg dm^{-3}	Ca	Mg	H+Al	SB	CTC	V %	m %	Sand (%)	Silt (%)	Clay (%)	CT*
				------------ $cmol_c$ dm^{-3} ------------										
6.2	2.0	13.9	194	2.40	1.28	1.90	4.2	6.1	69	0	38.3	2.9	58.8	Clayey

* Laboratory of Soil Analysis – Federal Institute of Education, Science, and Technology of Southern Minas Gerais, Machado Campus; *CT – Textural Class.

Source: Soil Analysis Laboratory, IFSULDEMINAS, Machado Campus (2017)

Table 2. Herbicide percentage efficacy table according to the SBCPD recommendations (1995)

Control Percentage	Control Description
90-100	Excellent or complete
80-89	Adequate; acceptable for the level of infestation
70-79	Moderate; insufficient for area infestation
50-69	Deficient or negligible
0-50	Lack of control

Source: SBCPD (1995); Fontes *et al*. (2006).

All experimental data were subjected to an F-test in the analysis of variance. When significance was detected, the data were grouped using the Scott-Knott mean grouping test (Scott, Knott, 1974). All statistical analyses were achieved at a 5% significance level. Although the resting time of the spray solution is a quantitative variable, the Scott-Knott test was also applied in this case, as grouping the means more easily discriminates the maximum storage time compared to regression analysis.

Results and discussion

The storage of solo glyphosate ready-mixed solutions for up to 168 hours (seven days) had no impact on the efficacy of the herbicide against sourgrass when applied at a spray volume of 240 L ha^{-1} (Table 3). In the evaluations conducted at 14 and 28 DAA, all treatments adequately controlled sourgrass, with damage increasing over time and no significant differences observed among treatments. This observation corroborates Rodrigues and Almeida (2005), who indicated that glyphosate doses starting at 720 g ha^{-1} are required to control non-resistant sourgrass. These results are also consistent with Ramos and Durigan (1998), who observed that the efficacy of glyphosate spray solutions remained unchanged even after 30 days of storage.

Regarding the mixtures, it was observed that the storage time of the spray solution showed no impact on performance of glyphosate when mixed with atrazine or 2,4-D. At 14 DAA, the average performance of the glyphosate + atrazine treatments was inferior in controlling sourgrass compared to glyphosate applied solo and glyphosate mixed with 2,4-D (Table 3). This discrepancy suggests the possibility of antagonism in the mixture containing glyphosate and atrazine. The literature reports antagonism between these products, possibly related more to the incompatibility of the spray solution formulations than to the physiological activity of the herbicides on plants (Appleby, Somabhi, 1978; Stahlman, Phillips, 1979; Vidal *et al*., 2003).

Regarding dry matter, both mixture treatments reduced the dry mass of sourgrass, differentiating them from the glyphosate solo application (Table 3). Given that 2,4-D and atrazine exhibit reduced activity on monocots, it is speculated that the mineral oil added to the spray solution may have enhanced glyphosate's efficacy, or that another adjuvant present in the commercial formulations of 2,4-D and atrazine may have contributed to this effect.

In the case of morning glory, after the application of treatments at a spray volume of 240 L ha^{-1}, it was observed that the glyphosate + 2,4-D mixtures resulted in better control at 14 and 28 DAA, outperforming the glyphosate + atrazine mixture (Table 4). The damage increased between the evaluation dates, so that at 28 DAA the glyphosate + 2,4-D mixture resulted in 100% control of morning glory for all spray solution rest periods. In this case, the storage time of the spray solution showed no impact on the performance of glyphosate solo, nor its mixtures with atrazine or 2,4-D (Table 4). The mean performance of the solo-glyphosate treatment was inferior compared to the control achieved by glyphosate + atrazine and glyphosate + 2,4-D, demonstrating satisfactory results for the herbicide mixtures compared to glyphosate solo. Moreover, evaluation of the dry matter mass of morning glory showed a significant differentiation for the glyphosate solo treatment compared to the other treatments, which did not differ among themselves (Table 4).

For soybean RR Syn 1059, evaluations of control at 14 and 28 DAA indicated that treatments with glyphosate + atrazine and glyphosate + 2,4-D adequately controlled the plants, with damage increasing over time and showing differentiation between treatments, with

Table 3. Percentage control and dry matter mass of sourgrass (*Digitaria insularis*) after the application of glyphosate spray solutions subjected to different storage periods after preparation, using glyphosate solo or glyphosate combined with atrazine or 2,4-D, sprayed at a spray volume of 240 L ha^{-1}. Machado – MG, 2015.

Storage periods after preparation	Glyphosate Condition			Mean
	Solo	Atrazine	2,4-D	
Percentage Control – 14 days after application				
1 hour	76.2	63.6	67.0	68.9
24 hours	76.6	64.6	69.0	70.1
48 hours	73.6	60.0	77.0	70.2
96 hours	68.6	73.2	77.2	73.0
168 hours	80.4	65.6	78.4	74.8
Mean	75.1 a	65.4 b	73.7 a	---
F_{gly} = 9.859**	F_t = 1.261^{NS}	F_{int} = 1.902^{NS}		CV(%) = 11.69
Percentage Control – 28 days after application				
1 hour	98.8	95.6	96.2	96.9
24 hours	97.8	97.6	92.4	95.9
48 hours	97.2	92.2	99.0	96.1
96 hours	97.4	97.2	95.6	96.7
168 hours	98.8	95.4	99.8	98.0
Mean	98.0	95.6	96.6	---
F_{gly} = 1.761^{NS}	F_t = 0.477^{NS}	F_{int} = 1.437^{NS}		CV(%) = 4.70
Dry Matter Mass[1] (g plot^{-1}) – 28 days after application				
1 hour	1.8	1.8	2.0	1.8
24 hours	2.4	1.9	2.2	2.2
48 hours	2.1	1.8	1.7	1.9
96 hours	2.7	1.4	1.7	1.9
168 hours	2.2	1.5	1.5	1.8
Mean	2.3 b	1.7 a	1.8 a	---
F_{gly} = 6.772**	F_t = 0.933^{NS}	F_{int} = 1.131^{NS}		CV(%) = 31.45

**Significant at 1% probability; NS – Not Significant; Data followed by the same letters within a row do not differ following the Scott-Knott mean grouping test at 5% significance; [1]Original data are presented after transformation by $\sqrt{x+1}$.

Source: authors (2015).

the greatest control obtained from the mixture with atrazine. As expected, no symptoms were observed in the Syn 1059 RR cultivar when glyphosate solo was applied. In this case, the storage time of the ready-mixed solution also showed no impact on the performance of glyphosate, whether applied solo or in mixtures with atrazine or 2,4-D (Table 5).

Roundup Ready (RR) soybean is tolerant to glyphosate due to an alteration in the enzyme 5-enolpyruvylshikimate 3-phosphate (EPSP) synthase, conferred by the introduction of a gene

Table 4. Percentage control and dry matter mass of morning glory (*Ipomoea triloba*) after the application of glyphosate spray solutions subjected to different storage periods after preparation, using glyphosate solo or glyphosate combined with atrazine or 2,4-D, sprayed at a spray volume of 240 L ha^{-1}. Machado – MG, 2015.

Storage periods after preparation	Glyphosate Condition			Mean
	Solo	Atrazine	2,4-D	
Percentage Control – 14 days after application				
1 hour	32.6	74.0	96.6	67.7
24 hours	36.0	68.4	95.8	66.7
48 hours	37.4	70.8	96.0	68.1
96 hours	34.6	73.0	93.4	67.0
168 hours	35.0	76.4	90.6	67.3
Mean	35.1 c	72.5 b	94.5 a	---
F_{gly} = 611.919**	F_t = 0.118^{NS}	F_{int} = 1.211^{NS}		CV(%) = 9.00
Percentage Control – 28 days after application				
1 hour	46.6	88.4	100.0	78.3
24 hours	55.0	89.2	100.0	81.4
48 hours	61.6	88.4	100.0	83.3
96 hours	62.6	87.0	100.0	83.2
168 hours	64.6	92.2	100.0	85.6
Mean	58.1 c	89.0 b	100.0 a	---
F_{gly} = 139.104**	F_t = 1.293^{NS}	F_{int} = 1.058^{NS}		CV(%) = 11.19
Dry Matter Mass[1] (g $plot^{-1}$) – 28 days after application				
1 hour	2.03	0.65	0.45	1.04
24 hours	1.66	0.55	0.40	0.87
48 hours	1.72	0.54	0.39	0.88
96 hours	1.45	0.56	0.57	0.86
168 hours	1.40	0.57	0.44	0.80
Mean	1.65 b	0.57 a	0.45 a	---
F_{gly} = 83.316**	F_t = 0.933^{NS}	F_{int} = 0.879^{NS}		CV(%) = 40.56

**Significant at 1% probability; NS – Not Significant; Data followed by the same letters within a row do not differ following the Scott-Knott mean grouping test at 5% significance; [1]Original data are presented after transformation by $\sqrt{x+1}$.

Source: authors (2015).

known as CP4 from an *Agrobacterium* species found in the soil, which confers insensitivity to EPSP (Madsen, Jensen, 1998; Trezzi, Kruse, Vidal, 2001). This characteristic enables glyphosate to be used as a selective herbicide for the crop, although it complicates management when volunteer glyphosate-resistant soybeans become the target of the application.

Employing a spray volume of 120 L ha^{-1}, no significant impact on the storage time of the ready-mixed solutions on herbicide efficacy—either when applied individually or in

Table 5. Percentage control and dry matter mass of glyphosate-resistant soybean (RR Syn1059) after application of glyphosate spray solutions subjected to different storage periods after preparation, using glyphosate solo or glyphosate combined with atrazine or 2,4-D, sprayed at a spray volume of 240 L ha^{-1}. Machado – MG, 2015.

Storage periods after preparation	Glyphosate Condition			Mean
	Solo	Atrazine	2,4-D	
Percentage Control – 14 days after application				
1 hour	0.0	99.2	84.2	61.1
24 hours	0.0	98.8	78.8	59.2
48 hours	0.0	99.0	86.2	61.7
96 hours	0.0	98.6	82.4	60.3
168 hours	0.0	98.8	82.2	60.3
Mean	0.0 c	98.9 a	82.8 b	---
F_{gly} = 2745.974**	F_t = 0.535^{NS}	F_{int} = 0.470^{NS}		CV(%) = 8.36
Percentage Control – 28 days after application				
1 hour	0.0	100.0	97.0	65.7
24 hours	0.0	100.0	99.8	66.6
48 hours	0.0	100.0	100.0	66.7
96 hours	0.0	100.0	100.0	66.7
168 hours	0.0	100.0	96.6	65.5
Mean	0.0 c	100.0 a	98.7 b	---
F_{gly} = 18608.112**	F_t = 1.121^{NS}	F_{int} = 1.121^{NS}		CV(%) = 3.17
Dry Matter Mass (g plot^{-1}) – 28 days after application				
1 hour	4.91	0.22	0.51	1.88
24 hours	5.40	0.25	0.57	2.07
48 hours	5.011	0.24	0.47	1.94
96 hours	5.28	0.26	0.48	2.01
168 hours	4.78	0.28	0.52	1.86
Mean	5.10 b	0.25 a	0.51 a	---
F_{gly} = 787.586**	F_t = 0.483^{NS}	F_{int} = 0.454^{NS}		CV(%) = 24.90

**Significant at 1% probability; NS – Not Significant; Data followed by the same letters within a row do not differ following the Scott-Knott mean grouping test at 5% significance.

Source: authors (2015).

mixtures—was identified, except for the residual dry matter of morning glory (Tables 6 and 7). For sourgrass, only an isolated herbicide effect was found regarding control at both 14 and 28 DAA. In this case, at 14 DAA, the application of glyphosate solo was more effective for controlling this species; at 28 DAA, glyphosate solo or glyphosate + atrazine achieved the highest control levels. At the lower spray volume, there was a slight indication of antagonism in the mixtures, particularly with 2,4-D (Table 6).

Regarding morning glory sprayed at 120 L ha^{-1}, no effect of spray solution storage time was detected on product efficacy in control evaluations at 14 and 28 DAA, nor was any

Table 6. Percentage control and dry matter mass of sourgrass (*Digitaria insularis*) after application of glyphosate spray solutions subjected to different storage periods after preparation, using glyphosate solo or glyphosate combined with atrazine or 2,4-D, sprayed at a low spray volume (120 L ha^{-1}). Machado – MG, 2017.

Storage periods after preparation	Glyphosate Condition			Mean
	Solo	Atrazine	2,4-D	
Percentage Control – 14 days after application				
1 hour	76.4	70.0	62.6	69.7
24 hours	71.0	53.6	72.2	65.6
48 hours	73.0	57.8	65.4	65.4
96 hours	73.4	65.4	62.6	67.1
168 hours	74.0	61.8	67.4	67.7
Mean	73.6 a	61.7 b	66.0 b	---
F_{gly} = 11.178**	F_t = 0.567^{NS}	F_{int} = 1.604^{NS}		CV(%) = 13.35
Percentage Control – 28 days after application				
1 hour	99.2	99.0	91.4	96.5
24 hours	99.0	89.2	96.2	94.8
48 hours	99.4	97.2	86.6	94.4
96 hours	99.0	98.4	82.4	93.2
168 hours	99.0	97.8	90.4	95.7
Mean	99.1 a	96.3 a	89.4 b	---
F_{gly} = 8.319**	F_t = 0.313^{NS}	F_{int} = 1.284^{NS}		CV(%) = 9.14
Dry Matter Mass[1] (g plot^{-1}) – 28 days after application				
1 hour	2.41	2.20	2.82	2.48
24 hours	2.66	2.43	2.33	2.47
48 hours	2.16	2.75	2.44	2.45
96 hours	2.60	2.47	2.59	2.55
168 hours	2.24	2.27	2.33	2.28
Mean	2.41	2.42	2.50	---
F_{gly} = 0.245^{NS}	F_t = 0.404^{NS}	F_{int} = 0.776^{NS}		CV(%) = 8.16

**Significant at 1% probability; NS – Not Significant; Data followed by the same letters within a row do not differ following the Scott-Knott mean grouping test at 5% significance; [1]Original data are presented after transformation by $\sqrt{x+1}$.

Source: authors (2017).

interaction with the mixtures observed. It is therefore evident that the storage period of the spray solution did not interfere with the efficacy of the active ingredients. Conversely, the highest control of morning glory was obtained when atrazine or 2,4-D was added to the spray solution (Table 7).

As for the dry matter mass of morning glory evaluated at 28 DAA, a differentiation was observed between the glyphosate solo treatment and the 2,4-D treatment. In this case, the mixture with 2,4-D at the longest storage time (168 hours) had lower efficacy than the other treatments, indicating an interaction between products with reduced performance only at 168 hours of storage. Tank mixtures are widely recognized as an important alternative for controlling sourgrass, morning glory, and volunteer soybean, yielding high efficacy (Maciel *et al*., 2011; Ramires *et al*., 2010). In practice, field applications frequently employ mixtures of glyphosate (720 g ha^{-1}) with atrazine (1,500 g ha^{-1}) or 2,4-D (670 g ha^{-1}) to broaden the control spectrum, resulting in improved efficacy against hard-to-control weeds—especially in corn crops—and to eliminate volunteer soybean (Monquero *et al*., 2001; Procópio *et al*., 2007; Shaw, Arnold, 2002; Vidrine, Griffin, Blouin, 2002).

Table 7. Percentage control and dry matter mass of morning glory (*Ipomoea triloba*) after application of glyphosate spray solutions subjected to different storage periods after preparation, using glyphosate solo or glyphosate combined with atrazine or 2,4-D, sprayed at a low spray volume (120 L ha^{-1}). Machado – MG, 2017.

Storage periods after preparation	Glyphosate Condition			Mean
	Solo	Atrazine	2,4-D	
Percentage Control – 14 days after application				
1 hour	89.8	98.8	99.2	95.9
24 hours	82.6	90.0	99.0	90.5
48 hours	95.2	99.0	99.2	97.8
96 hours	97.8	98.6	99.6	98.7
168 hours	85.2	99.6	99.4	94.7
Mean	90.1 b	97.2 a	99.3 a	---
F_{gly} = 7.994**	F_t = 2.119^{NS}	F_{int} = 0.944^{NS}		CV(%) = 8.89
Percentage Control – 28 days after application				
1 hour	94.0	99.6	100.0	97.9
24 hours	90.4	93.0	100.0	94.5
48 hours	92.0	100.0	100.0	97.3
96 hours	100.0	100.0	100.0	100.0
168 hours	90.4	100.0	100.0	96.8
Mean	93.4 b	98.5 a	100.0 a	---
F_{gly} = 7.419**	F_t = 1.455^{NS}	F_{int} = 0.831^{NS}		CV(%) = 6.58
Dry Matter Mass[1] (g $plot^{-1}$) – 28 days after application				
1 hour	0.87 B b	0.12 A a	0.19 A a	0.39
24 hours	0.69 B b	0.14 A a	0.30 A a	0.38
48 hours	0.36 A a	0.10 A a	0.18 A a	0.21
96 hours	0.73 B b	0.11 A a	0.13 A a	0.32
168 hours	0.27 A a	0.17 A a	0.76 B b	0.40
Mean	0.59	0.13	0.31	---
F_{gly} = 26.621**	F_t = 1.715^{NS}	F_{int} = 5.202**		CV(%) = 8.00

**Significant at 1% probability; NS – Not Significant; Data followed by the same letters within a row do not differ following the Scott-Knott mean grouping test at 5% significance; [1]Original data are presented after transformation by $\sqrt{x+1}$.

Source: authors (2017).

Conclusions

The storage duration of the ready-mixed herbicide solution had no significant impact on herbicide efficacy. Glyphosate solo provided the best control of sourgrass; mixtures of glyphosate with atrazine or 2,4-D most effectively controlled morning glory; and the glyphosate + atrazine and glyphosate + 2,4-D treatments achieved the highest control of volunteer transgenic soybean. Minor indications of antagonism were observed in the mixtures of glyphosate + atrazine and glyphosate + 2,4-D.

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