Research Article

The addition of adjuvants on glyphosate enhances the control of aquatic plant *Myriophyllum aquaticum* (Vell.)

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Conflict of Interest:
The authors declare that there is no conflict of interest regarding the publication of this manuscript.

HIGHLIGHTS

- The use of adjuvants in glyphosate to control aquatic plants is a viable technique allowing a reduction in herbicide doses.
- Control of the glyphosate alone was 85% at the dose of 7.5 L ha^{-1}, increasing to 100% when associated with Aterbane® and Veget'oil®.
- The addition of the adjuvants to glyphosate improved the control effectiveness of *M. aquaticum*.

ABSTRACT

Background: Knowledge about the action of glyphosate alone and associated with adjuvants in the effectiveness to control aquatic plants is important in the decision-making on its use.

Objective: This study aimed to evaluate the effectiveness of glyphosate and five adjuvants in the control of *Myriophyllum aquaticum*.

Methods: Glyphosate (Rodeo®) at doses of 1.5, 3.5, 5.5, and 7.5 L ha^{-1} was sprayed alone and associated with Aterbane® BR, Veget'oil®, Dash® HC, Assist®, and Agral® (0.5% v v^{-1}), in addition to the control, with a spray solution volume of 200 L ha^{-1}. The effectiveness of control was evaluated using the scores of a visual scale at 3, 7, 15, 21, 30, 45, and 60 days after application (DAA), regrowth, and dry matter accumulation at 60 DAA.

Results: The best effectiveness of control of the glyphosate alone was 85% at the dose of 7.5 L ha^{-1}, increasing to 100% when associated with Aterbane® and Veget'oil®. The control reached 100% for all glyphosate doses associated with Dash®. Moreover, glyphosate at the dose of 7.5 L ha^{-1} associated with Assist® provided a 98% control, while glyphosate doses of 3.5, 5.5, and 7.5 L ha^{-1} associated with Agral® provided a 100% control. Glyphosate at doses of 5.5 and 7.5 L ha^{-1} associated with Dash® and Agral® was more effective in reducing the regrowth and dry biomass (100%). Thus, glyphosate + Dash® and Agral® promoted the highest control (above 95%), the lowest regrowth, and the highest reduction in the dry biomass of *M. aquaticum*.

Conclusions: The addition of Aterbane® BR, Dash®, and Agral® to glyphosate improved the effectiveness of control of *M. aquaticum* and contributed to reducing the applied herbicide dose.

1 INTRODUCTION

The perennial and emerged aquatic plant *Myriophyllum aquaticum* (Vell.) belongs to the class Eudicots, order Myrtales, and family Haloragaceae, being originally from South America. It presents most of the submerged vegetative structure and only a part of the apical end is above the water surface. Its

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importance is associated with high biomass production capacity, which makes it a great competitor (Shafiullah and Lacroix, 2013).

Monospecific or poorly diversified colonization of macrophytes cause various environmental impacts, such as a decrease in the useful life of water bodies, such as loss of water due to excessive evapotranspiration, contributing to the aggradation by the accumulation of particulate material, altering the gas dynamics (CO_2 and O_2), and negatively affecting the multiple uses of water (Gettys et al., 2014; Cruz et al., 2015a).

The use of management measures, such as chemical control, which has great potential for use in Brazil, is necessary to minimize the losses. In this sense, Conama Resolution No. 467/2015 provides for the criteria for the authorization to use products or agents of physical, chemical, or biological processes to control organisms or contaminants in surface water bodies (Conama, 2015).

Among the herbicides that can be used, glyphosate (N-(phosphonomethyl) glycine) is effective in controlling macrophytes and is registered for use in aquatic environments in several countries (Givens et al., 2009; Gettys et al., 2014). It has been described as effective for *Myriophyllum aquaticum* (Negrisoli et al., 2003; Hofstra et al., 2006); *Urochloa subquadripara* and *Brachiaria mutica* (Carbonari et al., 2003); *Alternanthera philoxeroides*, *M. aquaticum, Eichhornia crassipes*, *Pistia stratiotes*, *Salvinia molesta*, and *Ludwigia grandiflora* (Emerine et al., 2010); and *E. crassipes*, *P. stratiotes*, *S. molesta*, *Salvinia herzogii* and *U. subquadripara* (Cruz et al., 2015b).

The biological effectiveness of herbicides is directly related to its contact with the target plant to be absorbed in the correct concentration and with a minimum of loss (drift) and a reduced risk of environmental contamination (Costa et al., 2014). The use of adjuvants added to the spray solution meets its specific demand relative to the physicochemical and biological properties, as it allows better distribution, deposition, and retention of droplets on the leaf surface and better product absorption and penetration in the weed (Decaro et al., 2016; Prado et al., 2016; Cunha et al., 2017).

Adjuvants have specific properties and their proper selection is important for an efficient application, considering the interaction with the chemical composition of leaves and the way this interaction occurs (Kissmann, 1998). Thus, these products are

divided into two groups: modifiers of the surface properties of liquids (e.g., surfactants, spreaders, humectants, detergents, dispersants, and adherents) and additives (e.g., mineral or vegetable oil, ammonium sulfate, and urea), altering the herbicide absorption due to its direct action on the leaf cuticle (Queiroz et al., 2008).

Knowledge about the action of glyphosate alone and associated with adjuvants is important in the decision-making on the effectiveness of its use to control aquatic plants, such as *M. aquaticum* in Brazilian water bodies. This aquatic plant is considered a competing, very aggressive invasive plant in certain environments due to its high capacity of incorporating biomass in water bodies (Cason and Roost, 2011). Thus, this study aimed to evaluate the biological effectiveness of the herbicide glyphosate alone and associated with five adjuvants to control *M. aquaticum* under greenhouse conditions.

2 MATERIAL AND METHODS

The herbicide used was glyphosate (480.0 g L^{-1}) in the formulation Rodeo® (Monsanto do Brasil Ltda.) and five adjuvants: Aterbane® BR (0.5% v v^{-1}) (a mixture of alkylphenol-polyglycol ether – ionic surfactant), Veget'oil® (0.5% v v^{-1}) (fatty acid esters of vegetable origin – vegetable oil); Dash® HC (0.5% v v^{-1}) (a mixture of methyl esters, aromatic hydrocarbon, unsaturated fatty acid, and surfactant); Assist® (0.5% v v^{-1}) (a mixture of paraffinic hydrocarbons, saturated and unsaturated paraffinic and aromatic rings from petroleum distillation), and Agral® (0.5% v v^{-1}) [Nonylphenoxy poly (ethyleneoxy) ethanol].

Plant cultivation was carried out in boxes with a capacity of 1000 liters filled with a substrate formed by coarse sand, organic fertilizer, and soil (1:1:2 v v^{-1}) and a continuous water flow. Three apical ends of *M. aquaticum* were transplanted into gerbox-type plastic boxes (11.0 cm in height and 15.0 cm in width) with a 2.5 L capacity filled with 0.5 L of substrate each. The applications were performed 15 days after transplanting.

Glyphosate was applied alone at doses of 1.5, 3.5, 5.5, and 7.5 L cp ha^{-1}, which are equivalent to 720, 1680, 2640, and 3600 g a.i. ha^{-1}, and associated with the adjuvants (0.5% v v^{-1}), in addition to the control without herbicide, totaling five replications. The applications were carried out with a precision CO_2-pressurized knapsack sprayer at a constant pressure of 172.36 KPa, equipped with a boom with

two DG 110.02 tips spaced at 0.5 m, with a spray solution consumption of 200 L ha^{-1}.

The environmental conditions at application consisted of a temperature of 32 ^{o}C, relative humidity of 55%, and wind speed of 1.5 km h^{-1}. The experiment was conducted in a completely randomized design. After the applications, the plants were maintained in a greenhouse with an average temperature of 28 ^{o}C and relative humidity of 60%.

Visual assessments of control effectiveness were performed at 3, 7, 15, 21, 30, 45, and 60 days after application (DAA), according to the score scale recommended by the Brazilian Society of Weed Science (SBCPD, 1995) and the Asociación Latinoamericana de Malezas (ALAM, 1974). The effectiveness scores corresponded to the average of three evaluators assigned individually. The number of regrowth was evaluated, and the percentage of regrowth was calculated relative to the control during the same period of evaluation of the control effectiveness. The regrowth count did not change the control effectiveness score measured by the evaluators. The regrowth rate was calculated by a simple percentage depending on the vegetative growth of the control. At the end of the 60 DAA experimental period and after draining excess water from the plants, the biomass was placed in a forced-air circulation oven at 70 ^{o}C for three days and the total dry mass (g) (with regrowth) was measured on a semi-analytical scale.

The results of effectiveness and dry matter were subjected to analysis of variance by the F-test (ANOVA) and the means were compared by the Tukey test at a 5% probability. The one-factor analysis was used to test the effect of doses within each adjuvant and evaluation time for the variable control effectiveness. Also, a 6×4 two-factor analysis (adjuvants × doses) was performed to test the effect of the interaction between adjuvants and doses for the variable control effectiveness at 60 DAA. The analyses were performed using the AgroEstat

computer system (Barbosa and Maldonado Junior, 2015).

3 RESULTS AND DISCUSSION

Glyphosate alone showed a significant difference in all tested doses for the control of *M. aquaticum* (Table 1). Glyphosate alone at a dose of 7.5 L cp ha^{-1} showed significant biological effectiveness of 30 and 70% control of *M. aquaticum* at 7, 15, and 21 DAA. Doses of 3.5 to 7.5 L ha^{-1} reached controls of 3.5 to 7.5 L ha^{-1} at 30 DAA, 10 to 80% at 45 DAA, and 15 to 85% at 60 DAA, respectively (Table 1). Similarly, Cruz et al. (2015b) found control of 80 to 100% of effectiveness for *E. crassipes*, *P. stratiotes*, *S. molesta*, *Salvinia herzogii*, and *U. subquadripara* at the dose of 8.0 L cp ha^{-1} of glyphosate in the formulation Rodeo$^®$ at 30 and 45 DAA.

The lowest number of regrowth with glyphosate alone occurred at the dose of 3.5 L ha^{-1}, with 26.6% at 15 DAA and 75% at 60 DAA relative to the control. The dose of 7.5 L ha^{-1} presented the highest percentage of regrowth, with values from 80% at 15 DAA to 185% at the last evaluation (60 DAA), which means a regrowth 85% higher than the vegetative growth of the control (Table 7). The glyphosate alone provided biomass of 3.12 g (67.8%) at the highest dose (7.5 L ha^{-1}) and 8.67 g (10.4%) at the dose of 1.5 L ha^{-1} (Table 8).

Glyphosate + 0.5% Aterbane BR$^®$ provided the highest control at the dose of 7.5 L ha^{-1} at 3 and 7 DAA (15 and 35%, respectively) and total control (100%) at the highest doses (5.5 and 7.5 L ha^{-1}) from 15 DAA (Table 2). The addition of the adjuvant provided an increase in the control rate in comparison with glyphosate alone, as the dose of 5.5 L ha^{-1} showed a 100% control at 15 DAA. Glyphosate is a systemic product that needs good absorption by the leaves, which does not necessarily imply good control, as it is directly related to the concentration translocated in the plant. In this case, the adjuvant contributed to increasing leaf surface wettability,

Table 1 - Effectiveness of glyphosate (Rodeo$^®$) alone to control *M. aquaticum*

Dose (L cp ha^{-1})		Days after application (DAA)						
		3	7	15	21	30	45	60
Glyphosate	1.5	0.0 a	0.0 b	0.0 b	0.0 b	0.0 c	0.0 d	0.0 d
Glyphosate	3.5	0.0 a	0.0 b	0.0 b	0.0 b	10.0 b	10.0 c	15.0 c
Glyphosate	5.5	0.0 a	0.0 b	0.0 b	0.0 b	10.0 b	15.0 b	19.0 b
Glyphosate	7.5	0.0 a	30.0 a	70.7 a	72.5 a	75.0 a	79.0 a	84.0 a
LSD		0	2.53	2.45	2.22	2.62	2.54	2.75
CV (%)		0	20.22	8.33	7.35	6.61	5.88	5.60
F Treatment		0	587.0	3457.2	4441.9	2893.6	3310.3	3044.6

CV = coefficient of variation.

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Table 2 - Effectiveness of glyphosate (Rodeo®) associated with Aterbane® BR to control *M. aquaticum*

Dose (L cp ha⁻¹)		Days after application (DAA)						
		3	7	15	21	30	45	60
Gly + Aterbane®	1.5	5.0 c	10.0 d	50.0 c	75.0 c	75.0 c	80.0 c	80.0 c
Gly + Aterbane®	3.5	5.0 c	20.0 c	60.0 b	80.0 b	85.0 b	90.0 b	94.5 b
Gly + Aterbane®	5.5	10.0 b	25.0 b	100 a	100 a	100 a	100 a	100 a
Gly + Aterbane®	7.5	15.0 a	35.0 a	100 a	100 a	100 a	100 a	100 a
LDS		1.90	0.61	5.37	3.33	3.22	3.04	3.04
CV (%)		13.03	1.62	4.16	2.25	2.15	1.97	1.95
F Treatment		105.8	4875.0	399.0	259.4	241.1	165.0	160.2

Gly = glyphosate (Rodeo®); CV = coefficient of variation.

reducing surface tension and droplet contact angle, and increasing cuticular penetration (Sherrick et al., 1986; Kruse et al., 2000).

The addition of 0.5% Aterbane® BR to glyphosate promoted control higher than 90% at the dose of 3.5 L ha⁻¹ (60 DAA). However, this association applied to an aquatic plant at a dose of 3,360 g a.i. ha⁻¹ (7.0 L ha⁻¹) reduced control to 81.50% at 26 DAA and 33.75% at 36 DAA due to the occurrence of regrowth (Negrisoli et al., 2003). The species *M. aquaticum* has morphological characteristics such as simple, pinnatipartite leaves with a central axis and a set of 6 to 18 segments on each side covered by a water-repellent waxy substance (Kissmann, 2000; Shafiullah and Lacroix, 2013), which makes it difficult the deposit and permanence of herbicide droplets.

The addition of Aterbane® BR in the herbicide solution with a dose of 3.5 L ha⁻¹ provided the lowest regrowth (20%) at 15 DAA and 125% at 60 DAA, while the glyphosate dose of 5.5 L ha⁻¹ promoted the highest regrowth (233.3%) relative to the control at 45 DAA. It shows that the adjuvant addition promoted a regrowth effect of 133.3% relative to the control (Table 7). Aterbane® BR also reduced biomass to 0.84 g (91.3%) at the dose of 1.5 L ha⁻¹, while the dose of 3.5 L ha⁻¹ promoted the highest value of dry biomass 2.14 g (77.9%) (Table 8).

Veget'oil® (0.5%) added to the glyphosate solution at the dose of 7.5 L ha⁻¹ provided better effectiveness, with 80% at 45 DAA and 90% at the last evaluation (60 DAA) (Table 3). This treatment compared to glyphosate alone showed similar behavior and the adjuvant addition only provided better effectiveness at lower doses. The time to obtain control is an important factor in the management of aquatic plants due to the release of nutrients in the water, which may contribute to the eutrophication of environments.

Glyphosate + Veget'oil® showed the lowest regrowth at 15 DAA at doses of 3.5 and 5.5 L ha⁻¹ (13.3%) and the highest percentage of regrowth at the dose of 1.5 L ha⁻¹ at all evaluations (Table 7). Moreover, Veget'oil® provided 1.77 g (81.7%) of dry biomass at 5.5 L ha⁻¹, while the dose of 1.5 L ha⁻¹ promoted the lowest dry biomass, with a value of 6.93 g (28.4%), thus corroborating with the high number of regrowth at this dose (Table 8).

Glyphosate + Dash® presented control of 10% at the dose 3.5 L ha⁻¹ at 3 DAA, 15% for all doses at 7 DAA, whereas glyphosate alone under the same conditions provided no control at doses of 1.5, 3.5, and 5.5 L ha⁻¹. The control reached 100% at the dose of 7.5 L ha⁻¹ at 15 DAA, 5.5 and 7.5 L ha⁻¹ at 21 DAA, and all doses at 30, 45, and 60 DAA, not differing statistically from each other (Table 4).

The adjuvant Dash® promoted the lowest regrowth using the glyphosate dose of 5.5 L ha⁻¹, with a percentage of regrowth varying from 5.0 to 6.6%. The highest percentage of regrowth occurred under a dose of 1.5 L ha⁻¹, ranging from 60 to 125% (Table 7).

Table 3 - Effectiveness of glyphosate (Rodeo®) associated with Veget'oil® to control *M. aquaticum*

Dose (L cp ha⁻¹)		Days after application (DAA)						
		3	7	15	21	30	45	60
Gly + Veget'oil®	1.5	0.0 a	0.0 c	0.0 d	0.0 c	0.0 d	0.0 d	0.0 c
Gly + Veget'oil®	3.5	0.0 a	1.7 b	2.5 c	10.0 b	25.0 c	60.0 c	75.0 b
Gly + Veget'oil®	5.5	0.0 a	2.3 b	5.5 b	10.0 b	30.0 b	75.0 b	80.0 b
Gly+ Veget'oil®	7.5	0.0 a	5.0 a	29.8 a	47.0 a	50.0 a	80.0 a	90.0 a
LSD		0	1.11	1.83	3.43	3.57	4.29	5.27
CV (%)		0.0	29.6	11.6	12.3	8.2	4.8	5.2
F Treatment		0.0	58.4	941.3	607.9	551.6	1226.8	1023.8

Gly = glyphosate (Rodeo®); CV = coefficient of variation.

The association that most promoted reduction in plant dry matter was the dose of 5.5 L ha⁻¹ + Dash®, with a value of 100% (Table 8).

Glyphosate + Assist® led to a control of 5% at 3 DAA using 5.5 and 7.5 L ha⁻¹, 30% at 7 DAA using 7.5 L ha⁻¹, 75 and 80% at 15 and 21 DAA using 5.5 and 7.5 L ha⁻¹, respectively, and 90, 95, and 98% at 30, 45, and 60 DAA using 7.5 L ha⁻¹, respectively (Table 5). The lowest number of regrowth occurred at 15 DAA using 1.5 and 3.5 L ha⁻¹, both with 40% regrowth relative to the growth rate in the control treatment, while the evaluation carried out at 45 DAA using 5.5 L ha⁻¹ presented the highest percentage of regrowth (194.4%) (Table 7).

The evaluation of biomass reduction showed that glyphosate + Assist® presented 1.63 g (83.2%) at the dose of 3.5 L ha⁻¹, while the highest number of regrowth (5.68 g or 41.3%) was observed at the dose of 1.5 L ha⁻¹ (Table 8).

The herbicide glyphosate + Agral® promoted 25% control at 5.5 L ha⁻¹ (3 DAA), 100% at 7.5 L ha⁻¹ (7 DAA), 100% at 3.5, 5.5, and 7.5 L ha⁻¹ (15, 21, 30, 45, and 60 DAA) (Table 6). The association with the non-ionic adjuvant (Agral®) promoted control higher than 89% at all tested doses (from 30 DAA), as observed for the same plant and adjuvant (94%) from 35 DAA and dose of 2240 g ha⁻¹ (Emerine et al., 2010). The molecule triclopyr at doses of 0.5 to 8.0 kg ha⁻¹ with no addition of adjuvant promoted a high control (100%) of *M. aquaticum* for a longer time (126 DAA) (Hofstra et al., 2006) when compared to this study.

Glyphosate + Agral® provided the lowest regrowth at the dose of 7.5 L ha⁻¹ at all evaluations, followed by 5.5 L ha⁻¹, as the highest number of regrowth was observed at the dose of 3.5 L ha⁻¹ (120% at 60 DAA) (Table 6). Agral® at a dose of 7.5 L ha⁻¹ reduced dry biomass by 100% (Table 8). Dash® and Agral® added to glyphosate were the adjuvants that most suppressed the regrowth process of *M. aquaticum*, both with 5.0% at doses of 5.5 and 7.5 L ha⁻¹, respectively (Table 7). However, this reduction in regrowth was lower than the glyphosate at a dose

Table 4 - Effectiveness of glyphosate (Rodeo®) associated with Dash® to control *M. aquaticum*

Dose (L cp ha⁻¹)		Days after application (DAA)						
		3	7	15	21	30	45	60
Gly + ash®	1.5	5.0 b	15.0 a	95.0 b	99.0 b	100 a	100 a	100 a
Gly + Dash®	3.5	10.0 a	15.0 a	98.2 a	99.0 b	100 a	100 a	100 a
Gly + Dash®	5.5	7.0 b	15.0 a	90.0 c	100 a	100 a	100 a	100 a
Gly + Dash®	7.5	5.0 b	15.0 a	100 a	100 a	100 a	100 a	100 a
LSD		2.65	3.07	2.4	0.86	0	0	0
CV (%)		23.6	12.3	1.5	0.5	0	0	0
F Treatment		13.2	0.0	55.4	7.5	0.0	0.0	0.0

Gly = glyphosate (Rodeo®); CV = coefficient of variation.

Table 5 - Effectiveness of glyphosate (Rodeo®) associated with Assist® to control *M. aquaticum*

Dose (L cp ha⁻¹)		Days after application (DAA)						
		3	7	15	21	30	45	60
Gly + Assist®	1.5	0.0 b	0.0 d	0.0 c	0.0 c	0.0 d	0.0 d	0.0 c
Gly + Assist®	3.5	0.0 b	5.0 c	30.0 b	35.0 b	50.3 c	75.0 c	80.0 b
Gly + Assist®	5.5	5.0 a	25.0 b	75.0 a	80.0 a	85.0 b	90.0 b	95.0 a
Gly + Assist®	7.5	5.0 a	30.0 a	75.0 a	80.0 a	90. a	94.3 a	97.3 a
LSD		1.14	2.87	3.16	2.79	2.79	3.13	2.75
CV (%)		27.33	11.48	4.22	3.43	2.97	2.9	2.43
F Treatment		107.1	438.2	2250.0	3227.7	3689.0	3288.9	4651.8

Gly = glyphosate (Rodeo®); CV = coefficient of variation.

Table 6 - Effectiveness of glyphosate (Rodeo®) associated with Agral® to control *M. aquaticum*

Dose (L cp ha⁻¹)		Days after application (DAA)						
		3	7	15	21	30	45	60
Gly + gral®	1.5	0.0 d	10.0 c	15.2 b	75.3 b	90.3 b	94.8 b	98.0 b
Gly + Agral®	3.5	15.0 b	95.0 b	100 a	100 a	100 a	100 a	100 a
Gly + Agral®	5.5	25.0 a	98.0 ab	100 a	100 a	100 a	100 a	100 a
Gly + Agral®	7.5	10.0 c	99.8 a	100 a	100 a	100 a	100 a	100 a
LSD		2.53	3.16	1.23	2.72	1.25	1.23	0.91
CV (%)		12.1	2.5	0.9	1.7	0.8	0.8	0.6
F Treatment		282.6	3197.4	19929.3	342.3	247.4	73.9	20.0

Gly = glyphosate (Rodeo®); CV = coefficient of variation.

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Table 7 - Regrowth (%) relative to the control of *M. aquaticum* after exposure to glyphosate alone and associated with adjuvants

Treatment	Dose (L cp ha⁻¹)	Days after application (DAA)				
		15	21	30	45	60
Vegetative growth of control	0.0	100.0	100.0	100.0	100.0	100.0
Gly	1.5	40.0	106.2	105.8	155.5	140.0
	3.5	26.6	25.0	35.3	72.2	75.0
	5.5	66.6	75.0	82.3	116.6	120.0
	7.5	80.0	106.2	141.2	188.9	185.0
Gly + Aterbane®	1.5	66.6	112.5	135.3	150	135.0
	3.5	20.0	43.7	64.7	138.9	125.0
	5.5	126.0	162.5	188.2	233.3	210.0
	7.5	80.0	87.5	129.4	144.4	160.0
Gly + Veget'oil®	1.5	106.6	118.7	158.8	194.4	180.0
	3.5	13.3	18.7	82.3	150.0	155.0
	5.5	13.3	12.5	64.7	88.9	90.0
	7.5	60.0	62.5	94.1	166.7	150.0
Gly + Dash®	1.5	60	131.2	129.4	127.8	25/125.0
	3.5	26.6	31.2	23.5	55.5	50.0
	5.5	6.6	6.2	5.9	5.5	5.0
	7.5	13.3	31.2	41.2	55.5	55.0
Gly + Assist®	1.5	40.0	75.0	94.1	94.4	85.0
	3.5	40.0	75.0	47.1	77.8	70.0
	5.5	53.3	56.2	164.7	194.4	175.0
	7.5	66.6	37.5	141.2	161.1	145.0
Gly + Agral®	1.5	53.3	56.25	52.9	122.2	135.0
	3.5	46.6	75	76.4	105.5	120.0
	5.5	13.3	12.5	17.6	27.8	30.0
	7.5	0.0	0.0	0.0	11.1	5.0

Gly = glyphosate (Rodeo®).

Table 8 - Average reduction of dry biomass (g) and percentage of reduction relative to the control (%) of *M. aquaticum* exposed to glyphosate alone and associated with adjuvants

Dose	Average reduction of dry biomass (%)					
(L ha⁻¹)	Gly	Gly + Aterbane®	Gly + Veget'oil®	Gly + Dash®	Gly + Assist®	Gly + Agral®
0.0	9.68(0.0)	9.68(0.0)	9.68(0.0)	9.68(0.0)	9.68(0.0)	9.68(0.0)
1.5	8.67(10.4)	0.84(91.3)	6.93(28.4)	0.57(94.1)	5.68(41.3)	1.61(83.4)
3.5	4.50(53.5)	2.14(77.9)	2.72(71.9)	0.16(98.3)	1.63(83.2)	0.82(91.5)
5.5	7.57(21.8)	2.02(79.1)	1.77(81.7)	0.00(100.0)	2.21(77.2)	0.25(97.4)
7.5	3.12(67.8)	2.12(78.1)	2.12(78.1)	0.40(95.9)	1.77(81.7)	0.00(100.0)

Gly = glyphosate (Rodeo®).

of 3.2 kg a.i. ha⁻¹ up to 30 DAA for *M. aquaticum* (Hofstra et al., 2006).

Also, the reduction was lower than that obtained with 2,4-D at doses of 670 and 1340 g a.i. ha⁻¹, which showed no regrowth until the end of the experiment (36 days), but higher than the diquat for *M. aquaticum* at doses of 102 and 204 g a.i. ha⁻¹, with a control equal to or higher than 80% at 6, 9, 11, 13, 17, and 20 DAA, which was reduced due to the emergence of sprouts (Negrisoli et al., 2003). According to these authors, the control effectiveness was reduced due to the appearance of regrowth, but its quantification is one more option for a better understanding of the *M. aquaticum* management.

The variation in regrowth from the lowest to the highest values (Table 7) is directly influenced by absorption, penetration through the cuticle, arrival, and action of the herbicide at the target site in the plant, but indirectly influenced by the plant species and age, environmental conditions, and herbicide and surfactant concentration in the spray solution (Satichivi et al., 2000).

The lowest reduction in dry biomass was 3.12 g (67.8%) for glyphosate alone, which was higher than the reduction observed by Hofstra et al. (2006), who found a value of 40.0% at the dose of 3.2 kg a.i. ha⁻¹ also using glyphosate. Also, it was higher for carfentrazone, with a reduction of 47.06%

Table 9 - Control of *M. aquaticum* after exposure to glyphosate alone and associated with adjuvants

Dose (L cp ha⁻¹)	Dose				LSD	F Treat.	CV (%)
	1.5	3.5	5.5	7.5			
Gly	0.0 Dc	15.0 Ce	19.0 Bd	84.0 Ac		2893.60**	
Gly + Aterbane®	80.0 Cb	94.5 Bb	100 Aa	100 Aa		186.15**	
Gly. + Dash®	100 Aa	100 Aa	100 Aa	100 Aa	2.5495	-	2.34
Gly. + Veget'oil®	0.0 Dc	75.0 Cd	80.0 Bc	90.0 Ab		3559.63**	
Gly. + Assist®	0.0 Dc	80.0 Cc	95.0 Bb	98.0 Aa		4448.37**	
Gly. + Agral®	98.0 Aa	100 Aa	100 Aa	100 Aa		2.09ᴺˢ	
LSD	2.8340						
F Treat.	5475.66**	2178.11**	2133.52**	95.69**			
CV (%)	2.34						

Gly. = glyphosate (Rodeo®). Means followed by uppercase letters in the column indicate a significant difference between treatments, while different lowercase letters in the row indicate a significant difference between doses.

at 100 µg L⁻¹ for *M. spicatum*, but lower than that obtained for the same plant, with a value of 82.0% at the same dose (100 µg L⁻¹), and lower than 2,4-D, which reduced the biomass of both plants to 0.00 g (100%) (Gray et al., 2007). The herbicide diquat promoted a reduction in dry biomass of 100.0% for *M. spicatum* and *Egeria densa* and 99.78% for *Potamogeton nodosus*, Stuckenia pectinata, and *Hydrilla verticillata* in a static system after three weeks with 0.37 mg L⁻¹ (Skogerboe et al., 2006).

Some surfactant adjuvants or not, such as Dash® and Agral®, can solubilize part of the wax existing on the leaf surface and influence the permeability of the cytoplasmic membrane (denaturing and precipitating proteins). It influences the impact of adhesion and retention of the sprayed droplets, increasing the spreading, wetting, and permeability of the cuticle or plasmalemma, which intensifies the absorption process (Knoche and Bukovac, 1992) and contributes for the herbicide to reach the specific site for plant control (bioavailability) at the effective concentration.

The order of effectiveness of glyphosate associated with adjuvant was Dash® > Agral® > Aterbane® > Assist® > Veget'oil® > herbicide without adjuvant. The lowest regrowth and dry biomass occurred with the addition of Dash® and Agral®. The high herbicide effectiveness with adjuvants (Aterbane®, Dash®, and Agral®) may be related to the high water solubility of glyphosate and the high water-soluble/fat-soluble balance of these adjuvants, which allowed for a better physicochemical association with glyphosate and, consequently, higher *M. aquaticum* control when compared to Veget'oil® and Assist®, which has low water-soluble/fat-soluble balance (Hess and Foy, 2000).

The interaction between factors adjuvant and doses showed significance (P<0.05) at 60 DAA, which indicates a different response between adjuvants as a function of dose. Dash® and Agral® showed the highest control effectiveness, regardless of the dose, while Aterbane®, Assist®, glyphosate alone, and Veget'oil® had dose-dependent effectiveness (Table 9). The highest control effectiveness was obtained with Dash® and Agral® at all glyphosate doses), Aterbane® BR at glyphosate doses of 5.5 and 7.5 g a.i. ha⁻¹), and Assist® at the dose of 7.5 g a.i. ha⁻¹) (Table 9).

4 CONCLUSIONS

The addition of the adjuvants Aterbane® BR, Dash®, and Agral® to glyphosate improved the control effectiveness of *M. aquaticum* and contributed to reducing the applied herbicide dose.

5 CONTRIBUTIONS

WRCJ: contributed to the structuring, writing, and statistics of the manuscript and conducting the study in the greenhouse; AFS: contributed to the structuring of the manuscript and conducting the study in the greenhouse; JHCC: contributed to the conduction of the study in a greenhouse; CC: contributed to the writing and structuring of the manuscript; RAP: contributed to the writing and provided the use of the NEPEAM-FCAV/UNESP facilities.

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