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Article

Efficacy of Imazamox with Centrifugal Energy Spray Nozzle on *Eichhornia crassipes* and Economic Analysis of Control Viability

*Eficácia do Imazamox com Bico de Pulverização de Energia Centrífuga em **Eichhornia crassipes** e Análise Econômica de Viabilidade de Controle*

GARLICH, N.[1]*
GUARNIERI, C.C.O.[1]
FREITAS, R.L.G.[1]
CERVONI, J.H.C.[2]
CRUZ, C.[2]
FERREIRA, M.C.[1]

ABSTRACT - The efficacy of imazamox to control *Eichhornia crassipes* with a centrifugal energy spray nozzle at doses and volumes of spray solution and the costs of mechanical and chemical control of aquatic plants were evaluated in this study. Imazamox doses consisted of 200, 400, and 600 g a.i. ha^{-1}, and spray solution volumes consisted of 25, 50, and 100 L ha^{-1}, with a control (without herbicide application) and ten replications. Applications were performed with a centrifugal energy spray nozzle. The evaluations were carried out considering the percentage of control at 7, 15, 21, and 30 days after application (DAA), and plant dry matter was measured at 30 DAA, as well as leaf retention of spray solutions. An efficacy from 96 to 100% and plant dry matter reduction from 88 to 100% was observed at 30 DAA using imazamox doses of 200, 400, and 600 g a.i. ha^{-1} and a spray solution volume of 50 L ha^{-1}. Imazamox doses and spray solution volumes were effective in controlling *E. crassipes*, except for 200 g a.i. ha^{-1} and 25 L ha^{-1}, respectively. The highest leaf retention of *E. crassipes* was 0.010 mL cm^2 at an imazamox dose of 400 g a.i. ha^{-1} and volume of 50 L ha^{-1}. The cost of chemical control was 20 times lower when compared to mechanical control, making it economically more viable. These results are important for decision-making on which method and application technology should be used to control *E. crassipes*.

Keywords: application technology, *Eichhornia crassipes*, common water hyacinth, management.

*RESUMO - Neste estudo foi avaliada a eficácia do imazamox para controle de **E. crassipes**, com bico de pulverização de energia centrífuga em doses e volumes de calda de pulverização e comparação do custo de controle mecânico e químico de plantas aquáticas. Foram utilizadas as doses de 200, 400 e 600 g i.a. ha^{-1} de imazamox e volumes de calda de 25, 50 e 100 L ha^{-1}, além de um controle (sem aplicação do herbicida), com dez repetições. As aplicações foram feitas com bico de pulverização de energia centrífuga. As avaliações foram realizadas por porcentagem de controle em 7, 15, 21 e 30 dias após a aplicação (DAA), e a massa seca das plantas foi mensurada aos 30 DAA, assim como a retenção foliar das caldas de pulverização. Aos 30 DAA, em 200, 400 e 600 g i.a. ha^{-1} e 50 L ha^{-1}, ocorreu eficácia de 96% a 100% e redução da massa seca das plantas de 88% a 100%. As doses e volumes de calda do imazamox foram eficazes no controle de **E. crassipes**, exceto 200 g i.a. ha^{-1} e 25 L ha^{-1}. A maior retenção foliar do aguapé foi de 0,010 mL cm² na concentração de 400 g i.a. ha^{-1} e 50 L ha^{-1}. O custo do controle químico foi 20 vezes menor que o mecânico, o que o torna economicamente mais viável que este. Esses resultados são importantes para a tomada de decisão sobre qual método e tecnologia de aplicação devem ser utilizados no controle de **E. crassipes**.*

Palavras-chave: tecnologia de aplicação, *Eichhornia crassipes*, aguapé, manejo.

*** Corresponding author:**
<nathalia.garlich@gmail.com>

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[1] Universidade Estadual de São Paulo, UNESP, Jaboticabal-SP, Brasil; [2] Centro Universitário da Fundação Educacional de Barretos, UNIFEB, Barretos-SP, Brasil.

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INTRODUCTION

Floating aquatic plants cause serious problems to water bodies due to their rapid vegetative multiplication (Marchi et al., 2011). Common water hyacinth (*Eichhornia crassipes*, Pontederiaceae) is one of the main weeds because it reproduces by seeds, vegetatively, and via stolons (Villamagna and Murphy, 2010), damaging navigation, tourism, fishing, and power generation in hydroelectric plants, besides being used as a place for reproduction of insect vectors of diseases such as dengue fever, yellow fever, and malaria (Gettys et al., 2014; Mudge et al., 2016), which justifies the use of control methods.

In Brazil, due to operational conditions and environmental restrictions, mechanical control is the most commonly used alternative. However, the cost to remove the macrophytes *E. crassipes* and *Brachiaria arrecta* in a 276 hectares reservoir was high, exceeding USD 50,000 per month (Antuniassi et al., 2002).

Chemical control has been evaluated for the control of aquatic plants due to its effectiveness and better cost-benefit relationship (Gettys et al., 2014). Control operating costs with herbicides can be 61 to 90% lower when compared to mechanical control (Cave, 1981; Raju and Reddy, 1988).

The legal viability of this control method occurred on July 16, 2015, with the publication of Resolution No. 467, which provides for the control of the use of products or processes for the recovery of water environments and provides other measures (CONAMA, 2015), thus allowing the chemical control.

One of the herbicides indicated to control aquatic plants is imazamox, which belongs to the chemical group of imidazolinones, an inhibitor of ALS (acetolactate synthase) (Senseman, 2007), as it demonstrates 90% effectiveness to control *E. crassipes* (Emerine et al., 2010; Campos et al., 2012; Campos et al., 2013; Gettys et al., 2014) and has no restrictions on the use of treated water for ingestion, fishing, swimming, and minimal restrictions for irrigation. In the environment, imazamox is not toxic to aquatic invertebrates, bees, fish, birds, and mammals, besides being little toxic to algae. It does not present bioaccumulation, has a half-life of 5 to 15 days depending on the luminosity and depth of the water body, and its dissipation occurs by dilution and photolysis (Rodgers and Black, 2012).

Application technology interferes with herbicide efficiency for controlling aquatic plants and environmental safety. The use of rotating nozzles can contribute to efficiency by producing droplets of uniform size, reducing the potential risk of drift and allowing the reduction of application volume when compared to spraying with hydraulic nozzles (Barbosa et al., 2011).

However, little information can be found relating the minimum volume of spray solution, leaf retention, and adequate amount of active ingredient to be used in aquatic plants. This knowledge guides the rational use of herbicide with less presence of residues in water bodies, being essential in the management decision making. Thus, this study aimed to evaluate the efficacy of the herbicide imazamox in the control of *E. crassipes* with controlled droplet application (CDA) at doses and volumes of spray solution, as well as compare the cost of chemical and mechanical controls.

MATERIAL AND METHODS

Efficacy of imazamox

Plants of *E. crassipes* were grown in 250 L plastic boxes, and young plants (new stolons) were transplanted into 2.5 L plastic containers filled with a substrate composed of coarse sand, organic fertilizer, and soil (1:1:2 v v^{-1}) and maintained in a greenhouse.

After occupying 75% of the area of the plastic box with macrophytes containing five to seven leaves, imazamox (BAS 720 01 H - Basf, 120 g a.i. L^{-1}) was applied. The application was performed with a centrifugal energy spray nozzle model Herbi®-4 (Micron Sprayers Limited), with a rotation of 134.16 g force (2,000 rpm min^{-1}), flow rate of 0.1 L min^{-1}, and pressure exerted by gravity.

Imazamox doses consisted of 200, 400, and 600 g a.i. ha^{-1}, while spray solution volumes were 25 L ha^{-1} with a speed of 2.0 m s^{-1}, 50 L ha^{-1} with a speed of 1.0 m s^{-1}, and 100 L ha^{-1} with a speed of 0.5 m s^{-1}, in addition to a control without herbicide application and ten replications per treatment, totaling 10 treatments and 100 experimental units in a completely randomized design.

After application, the macrophytes were transferred to a greenhouse (mean temperature of 27.0±2.0 °C). Efficacy was evaluated by control scores, where zero corresponded to no plant injury and 100 to plant death, attributed by four evaluators, constituting a mean (SBCPD, 1995). Evaluations were performed at 7, 15, 21, and 30 days after application (DAA). Plant dry matter (g) were evaluated at the end of the experimental period by drying the plants in a forced air circulation oven at 65 °C until constant weight.

Leaf retention analysis

Three leaves of common water hyacinth were used per treatment in a completely randomized design to evaluate the leaf retention capacity of *E. crassipes*, in addition to the drainage point, as a function of leaf size and spray solutions used in the experiment.

These leaves were positioned vertically on a support placed on a semi-analytical balance with 1.0 mg precision. The leaves were sprayed using a hollow cone hydraulic spray nozzle model Teejet TXVK8002 at a pressure of 300 kPa until the liquid flowed through the leaf surface. After draining, the mass of spray solution retained on the leaves (g) was recorded, being considered the maximum amount of liquid that the leaves can retain (Matuo and Baba, 1981). Liquid density can be considered equal to 1 and, therefore, mass is equal to volume (Barbosa et al., 2013).

Leaf area of plants was calculated in an electronic surface integrator (LICOR LI-3100) after spraying the herbicide on the leaves, providing the real leaf area (RLA) directly in square centimeters, and the leaf retention data were expressed in mL cm^{-2}.

Cost of chemical and mechanical control

A simulation was performed between the mechanical and chemical methods to evaluate the cost of aquatic plant control.

The data of operating costs obtained in the literature according to Scheer et al. (2016), whose operating capacity measurement consisted of the time for loading of a Mercedes Bens 2423 truck (grouping of partially densified macrophytes in the water body by a C96-4 water dozer CONVER® mowing boat and removed by a Caterpillar 320C excavator), transport to and from disposal areas, and unloading in them (dumping), were used for the mechanical method.

For the chemical method, a comparison was performed between the operating capacity and cost of imazamox application considering the best dose and spray solution volume evaluated in this study, according to polynomial regression analysis (imazamox dose of 273 g a.i. ha^{-1} and volume of 35 L ha^{-1}) (Figure 1).

Statistical analysis

The results of the percentage of control of the aquatic plant, dry matter, and leaf retention were submitted to analysis of variance, and means were compared by the Tukey's test ($p>0.05$). The percentages of efficacy and dry matter were submitted to the polynomial regression analysis in software Agroestat (Barbosa and Maldonado, 2014).

RESULTS AND DISCUSSION

Efficacy of control

Imazamox presented a control lower than 5% at 7 DAA, but with initial signs of intoxication (leaf edge chlorosis and initial plant bulb necrosis) at all doses and volumes (Table 1). This herbicide provided 14.50% control of *E. crassipes* with a dose of 290.4 g a.i. ha^{-1} and spray solution volume of 200 L ha^{-1} (Campos et al., 2012), and 10.75% control with a dose of 290 g a.i. ha^{-1} and volume of 0.03 mL (droplet) on a leaf of common water hyacinth at 7 DAA (Campos et al., 2013). This low percentage of control at 7 DAA is due to the mechanism of action of the herbicide, which is an inhibitor of ALS synthesis. The effects on the target plant commonly manifest after a period of seven to eight days (Senseman, 2007).

A significant difference was observed between doses and spray solution volumes evaluated at 14 DAA. The highest percentages of control, with values of 43.60 and 51.20%, were observed with doses of 400 and 600 g a.i. ha^{-1} volume of 50 L ha^{-1}, respectively (Table 1). A significant difference was also observed with a dose of 600 g a.i. ha^{-1} and spray solution volume of 25 L ha^{-1} at 21 DAA, reaching a plant control of 86.80% (Table 1). A control from 86.80 to 89.50% was observed with a spray solution volume of 50 L ha^{-1} and doses of 200, 400, and 600 g a.i. ha^{-1} and 92 and 94.50% with doses of 400 and 600 g a.i. ha^{-1} and volume of 100 L ha^{-1}, which is considered excellent (Table 1).

Table 1 **-** Percentage of control at 7, 14, 21, and 30 days after application (DAA) of the herbicide imazamox and total dry matter and percentage of dry matter reduction of *E. crassipes* plants at 30 DAA

Treatment (g a.i. ha^{-1}/L ha^{-1})	Percentage of control (%) in DAA				Dry matter (g)	Reduction (%)
	7	14	21	30		
200/25	2.10 abc	7.60 c	16.50 c	26.50 b	13.55 b	43.27
400/25	2.70 ab	15.60 bc	78.50 ab	86.30 a	3.15 cd	86.83
600/25	3.00 ab	31.70 ab	86.80 ab	93.30 a	1.76 cd	92.60
200/50	4.40 a	40.00 a	86.80 ab	95.70 a	2.65 cd	88.92
400/50	4.60 a	43.60 a	89.50 ab	97.00 a	0.68 cd	97.16
600/50	3.00 ab	51.20 a	87.50 ab	100.00 a	0.0 d	100.00
200/100	1.30 bc	2.80 c	69.50 b	82.00 a	5.51 c	76.91
400/100	1.80 bc	3.80 c	92.00 ab	98.70 a	0.71 cd	97.03
600/100	4.40 a	16.20 bc	94.50 a	99.80 a	0.05 d	99.75
Control	0.00 d	0.00 d	0.00 d	0.00 d	23.96 a	0
F Treatment	7.35**	18.47**	39.29**	56.41**	49.98**	-
CV (%)	63.70	65.30	24.20	19.00	66.45	-
LSD (5%)	2.52	20.12	24.62	24.62	5.01	-

** Significant at 1% probability. Means followed by the same lowercase letter in the column do not differ statistically from each other by the Tukey's test ($p>0.05$).

All the tested doses and spray solution volumes were effective to control *E. crassipes* at 30 DAA, except for the dose of 200 g a.i. ha^{-1} and volume of 25 L ha^{-1}. All other treatments resulted in a control higher than 80%, standing out the application volume of 50 L ha^{-1}, with a control higher than 95% (Table 1). A control of 97.75% of *E. crassipes* was reached with an imazamox dose of 290.4 g ha^{-1} and volume of 200 L ha^{-1} at 35 DAA (Campos et al., 2012), a volume four times higher than that used in this study. The use of 50 L ha^{-1} was as effective as 200 L ha^{-1}, which allows the application of lower spray solution volumes, thus reducing economic and environmental impacts.

Imazapyr doses of 266.30, 532.60, and 665.75 g a.i. ha^{-1} and a spray solution volume of 200 L ha^{-1} at 30 DAA controlled 80% of *E. crassipes* (Cruz et al., 2015), which is different from that observed in this study, in which imazamox controlled from 96 to 100% of plants with 50 L ha^{-1}. This difference in control can be attributed to the technology chosen for herbicide application. The use of rotating nozzles can provide a better control efficiency by producing uniform-size droplets with low spray solution volumes and reducing the potential risk of drift when compared to hydraulic nozzles (Barbosa et al., 2011).

A dose of 600 g a.i. ha^{-1} and spray solution volume of 50 L ha^{-1} controlled 100% of plants (Table 1). Also, imazamox and imazapyr doses of 560 g a.i. ha^{-1} + 0,25% nonionic surfactant and volume of 280 L ha^{-1} led to controls of 94 and 79% of *E. crassipes* plants at 35 DAA, respectively

(Emerine et al., 2010), which means the use of an application volume four times higher. Spray solution volumes above that required increase application costs and can lead to the deposition of droplets out of the target, potentiating the risk of drift to the aquatic environment.

The use of the rotating nozzle with a volume of 50 L ha^{-1} provided control similar to that of a CO_2-pressurized with a hydraulic tip with 200 and 280 L ha^{-1} (Emerine et al., 2010; Campos et al., 2012). The application of lower spray solution volumes reduces the economic and environmental impacts since volumes above the necessary can cause drift and drainage, with higher risks to the environment (Barbosa et al., 2011).

Control effectiveness of doses used in the mentioned studies is similar to that observed in the present study. However, spray solution volumes commonly used are higher. Thus, the volume of 50 L ha^{-1} had no negative influence on the control of *E. crassipes*, showing that lower spray solution volumes can be used, thus reducing costs. Because leaf retentions are similar, a higher spray solution volume may mean higher drainage. Therefore, lower volumes can be considered safer for use in the aquatic environment, reducing the risk of contamination.

Doses of 200, 400, and 600 g a.i. ha^{-1} and spray solution volume of 50 L ha^{-1} provided dry matter reduction of *E. crassipes* from 88 to 100% (Table 1). The dose of 560 g a.i. ha^{-1} + 0,25% nonionic surfactant and volume of 280 L ha^{-1} reduced 61.10% of the *E. crassipes* plants (Emerine et al., 2010). These values were lower when compared to those observed in the present study using a dose of 200 g a.i. ha^{-1} and a volume of 50 L ha^{-1}, which shows that a spray solution volumes around 50 L ha^{-1} are feasible as long as it is used the appropriate application technology.

The regression analysis between imazamox doses and percentage of control showed that the theoretical concentration of 273 g a.i. ha^{-1} could provide 80% efficacy in the control of *E. crassipes* (Figure 1A). For imazamox doses as a function of plant dry matter, the theoretical dose to obtain 80% reduction of plant dry matter was 230 g a.i. ha^{-1} (Figure 1B).

According to the regression analysis between the spray solution volume and the percentage of control of *E. crassipes* plants, as well as considering the scoring scale of SBCPD (1995), the volume that provides 80% control of *E. crassipes* is 35 L ha^{-1} (Figure 1C). For spray solution volume as a function of plant dry matter, the theoretical volume was 30 L ha^{-1} for reduction higher than or equal to 80% in dry matter (Figure 1D). From these correlations and considering the studied factors, an efficacy higher than 95% verified for an application volume of 50 L ha^{-1} is justified. The application volume of 35 L ha^{-1} and an imazamox dose of 273 g a.i. ha^{-1} were considered for calculating the cost, considering as sufficient the percentage of reduction of *E. crassipes* equal to 80%.

Leaf retention

The highest leaf retention of *E. crassipes* plants occurred at a dose of 400 g a.i. ha^{-1} and spray solution volume of 50 L ha^{-1}, with a value of 0.010 mL cm^{-2}, when compared to the control, with a value of 0.008 mL cm^{-2} (Table 2). The lowest values of leaf retention were observed at a dose of 200 g a.i. ha^{-1} and volume of 25 L ha^{-1}, with a value of 0.005 mL cm^{2}, as well as at a dose of 600 g a.i. ha^{-1} and volume of 25 L ha^{-1}, with a value of 0.004 mL cm^{-2}, when compared to the control (Table 2). Leaf retention of a spray solution with dye in macrophytes *E. crassipes* and *Pistia stratiotes* was 0.40 and 720 mL cm^{-2} (Marchi et al., 2009a, b), which is higher when compared to that found in this study (0.010 mL cm^{-2}) and lower for *Salvinia auriculata*, with a value 0.001 mL cm^{-2} (Marchi et al., 2011). Due to the low leaf retention of *E. crassipes*, the application technology adopted for its control must be well known to avoid drainage of the spray solution and correct the deposition of the pesticide on the target without causing contamination of the aquatic environment.

In this study, no change in leaf retention was observed in relation to the increased herbicide dose in the spray solution (Table 2) due to the combination of the spray solution and leaf surface characteristics. Because herbicide formulation is water based without surfactants, variations in its concentration do not alter leaf retention.

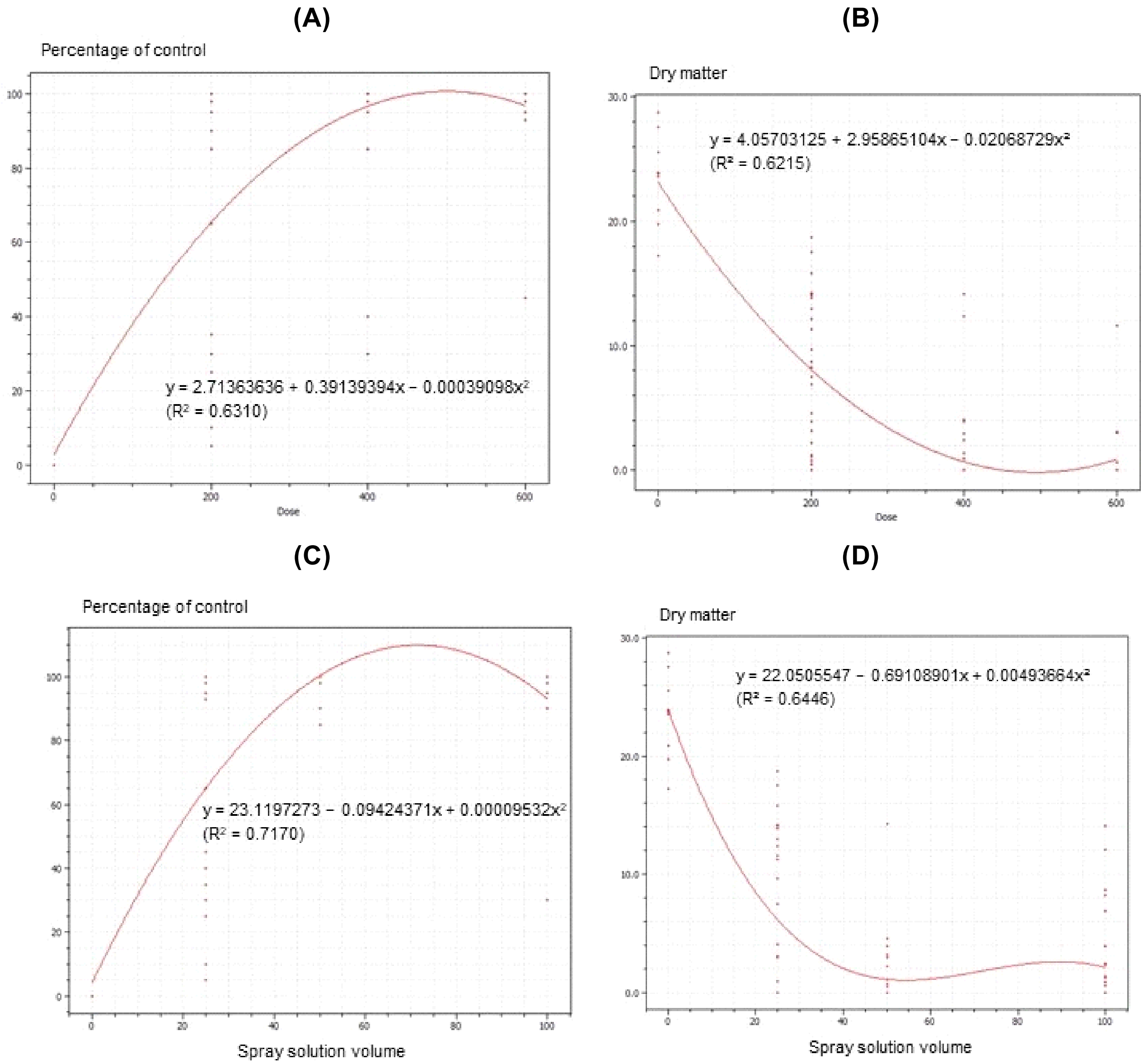

Figure 1 - Regression analysis of imazamox doses (g a.i. ha^{-1}) and percentage of control (%) of *E. crassipes* (A). Regression analysis of imazamox doses (g a.i. ha^{-1}) and dry matter (g) of *E. crassipes* (B). Regression analysis of spray solution volumes (L ha^{-1}) and percentage of control (%) of *E. crassipes* (C). Regression analysis of spray solution volumes (L ha^{-1}) and dry matter (g) of *E. crassipes* (D).

Cost of chemical and mechanical control

The operating capacity for mechanical removal was low (0.15 ha day^{-1}), and the cost reached R$ 51,640.00 ha^{-1} (Table 3). The estimated operating capacity for the chemical control of 10.0 ha day^{-1} was almost 20 times lower (R$ 2,622.00 ha^{-1}), considering an imazamox dose of 273 g a.i. ha^{-1} and a spray solution volume of 35 L ha^{-1}. The results of this simulation are similar to those found by Cave (1981), who observed that the use of glyphosate and different equipment to control macrophytes corresponded to 10% of the cost of mechanical control. Antuniassi et al. (2002) found that the monthly cost of the mechanical removal of macrophytes *E. crassipes* and *B. arrecta* was USD 54,055.53, while the cost of chemical control was USD 122.70, equivalent to 0.23% of the mechanical control.

The choice of method to be used for controlling aquatic plants depends on its efficiency and operating cost. In the literature, the mechanical removal of aquatic plants is the main form adopted in Brazil (Antuniassi et al., 2002). However, following the adoption of the Resolution

No. 467, which authorizes the use of herbicide products to control aquatic plants in water bodies (CONAMA, 2015), it is necessary to compare the costs between chemical and mechanical control for decision-making on which method is the most economically viable, effective, and safe in environmental management.

Considering these results, the application volume of 50 L ha^{-1} and an imazamox dose of 200 g ha^{-1} (control higher than 95%), applied with a centrifugal energy nozzle, were effective to control *E. crassipes*, being economically more feasible than mechanical control. These results are important as they contribute to decision-making on which method and application technology should be used to control *E. crassipes*, contributing to more rational and effective use of resources and minimizing the impacts on the aquatic environment.

Table 2 **-** Leaf retention of spray solutions used to control *E. crassipes* (mL cm^{-2})

Dose (g a.i. ha^{-1})	Application volume (L ha^{-1})	mL cm^{-2}
200	25	0.005 b
400		0.006 ab
600		0.004 b
200	50	0.007 ab
400		0.010 a
600		0.008 ab
200	100	0.007 ab
400		0.006 ab
600		0.006 ab
Control	-	0.008 ab
F treatment	-	3.31*
CV (%)	-	21.4
LSD (5%)	-	0.0045

* Significant at 5% probability. Means followed by the same lowercase letter in the column do not differ statistically from each other by the Tukey's test (p>0.05).

Table 3 **-** Simulation of costs of mechanical removal in comparison to the cost simulating the chemical control with the herbicide imazamox

Mechanical removal of *E. crassipes* plants (Scheer et al., 2016)					Cost (R$ ha^{-1})
Equipment	R$/machine hour	Daily rate (R$)	OC (m^3 day^{-1})**	OC (ha day^{-1})	
Caterpillar 320C excavator	415	3320	-	-	-
Dump truck	207.00	1660.00	-	-	-
Dump truck	207.00	1660.00	-	-	-
Mowing boat	138.00	1106.00	-	-	-
Total	-	7746.00	132	0.15	51,640.00
Chemical control with herbicide spraying					
Boat for spraying	138.00	1660.00	-	-	
Support boat	70.00	560.00	-	-	
Herbicide*	1000	24.000	-	-	
Total	-	26,220.00	-	10***	2,622.00

* Herbicide cost is hypothetical and well above the average value of the herbicide in the market since the product is still in the registration phase. ** Considering 11.5 m^2 m^{-3}. *** Considering 1.25 hectare $hour^{-1}$ in 8 hours of work. OC -operating capacity.

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