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# Efficacy of Glyphosate in Water Management and the Effects on Water Quality

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## Abstract

The present work aimed to evaluate the behavior of glyphosate herbicide in aquatic environment, considering some water quality parameters, in reservoir conditions without flow and without replacement of evapotranspired water. Twenty reservoirs (polyethylene water tanks) with a storage capacity of 1000 liters were used. The recommended herbicide dose according to the manufacturer was 7.0 L or 3360 grams of acid equivalent per hectare. For application in the reservoirs, a precision equipment was used to carbon dioxide ($CO_2$), providing a flow of 200 $L \cdot ha^{-1}$. Freezing macrophyte death was achieved by storing the plants in a freezer at −18˚C for a period of 48 hours. The analyses of control efficiency were performed at 7, 14, 21, 28, 35 and 42 days after application (DAA). Water samples for analysis of quality indicators, pH and dissolved oxygen were collected weekly for nine weeks. The obtained result allows concluding that the herbicide glyphosate presented excellent control efficiency of water hyacinth and did not significantly alter the water quality parameters pH and dissolved oxygen, indicating its use in the management of this macrophyte.

## Keywords

Herbicide, pH, Dissolved Oxygen, Environmental Impact

## 1. Introduction

The floating aquatic macrophyte *Eichhornia crassipes* is considered one of the biggest problems in the tropics and subtropics water bodies. It originates from the Amazon and has dispersed very rapidly in various tropical and subtropical countries in Latin America and the Caribbean, Africa, Southeast Asia and the Pacific [1] [2].

The water hyacinth, in the condition of weeds, causes damage to ecosystems, which may cause loss of biodiversity and may suppress or increase the presence of native species. It also causes losses to the generation of electric energy; navigation; water catchment; agricultural activity; fishing activity; public health; leisure and tourism and environment [3]-[10].

The water hyacinth has a fast multiplication capacity, a large area of photosynthetic tissue in proportion to the plant length, a large capacity to occupy places with light incidence, as well as independence of substrate conditions due to water flow and plant location. Its explosive growth is largely due to the eutrophication of water bodies and also the absence of natural enemies of the plant contributes to its rapid growth [2] [11].

Thus, the management or control of aquatic macrophytes becomes necessary to minimize interference in the biotic balance or multiple uses of the water environment. Among the methods considered for this purpose, chemical control is the one that has been used the most in different places in the world [12].

The most widely used herbicides worldwide for aquatic macrophyte control are: 2,4-D; diquat; endothal, copper based compound; fluridone; imazapyr and glyphosate. It also highlights that, in Brazil, the most used are glyphosate and 2,4-D [13].

Several studies point to the high efficiency of glyphosate control in water hyacinth management [14] [15] [16] [17] [18]. As for the behavior of the herbicide in the aquatic environment, it undergoes photodegradation, microbial degradation, adsorption by particulate organic matter and suspended clays, dilution by tributaries contributions and half-life of a few hours to a few days [19]-[25].

However, given the possible risks that macrophyte control with herbicides may provide, this study aimed to evaluate the possible impacts caused by glyphosate application in the control of *Eichhornia crassipes*, in some water quality parameters, under reservoir conditions without water flow without replacement of the evapotranspired water.

## 2. Material and Methods

The study is developed in the Experimental Area of the Faculty of Agricultural Engineering/UNICAMP, during the months July 2018 to January 2019. Reservoirs of 1000 liters were placed, composing 5 treatments with 4 replications, totaling 20 experimental plots, with randomized block design.

In the reservoirs there was no replacement of evapotranspired water. Adult water hyacinth plants were used in the experiment, providing 90% of surface occupation on the reservoir.

### 2.1. Treatments

The reservoirs received water hyacinth plants controlled by glyphosate and freezing, plants without any control and reservoirs without herbicide and with the presence of the product.

Glyphosate was used in formulation Glyphosate Transorb®. This product contains 648 $g \cdot L^{-1}$ of isopropylamine salt of N-(phosphonomethyl) glycine with 480 $g \cdot L^{-1}$ of acid equivalent. The dose was 7.0 $L \cdot ha^{-1}$ or 3360 g of acid equivalent per ha.

The applications were done by precision backpack sprayer at $CO_2$ constant pressure of 2 $kgf \cdot cm^{-2}$ (20 Kpa) and spray solution consumption of 200 $L \cdot ha^{-1}$. The applications were done with an initial temperature ranging from 22˚C to 24˚C, relative humidity between 60% and 70% and wind speed 0.5 to 2.0 $km \cdot h^{-1}$.

The death of macrophyte by freezing was performed for a period of 24 hours, at −18˚C, with subsequent placement of the plants in their reservoirs.

### 2.2. Evaluations

Efficiency evaluations were performed visually at 7, 14, 21, 28, 35 and 42 days after application (DAA), using the percentage scale where 0 (zero) represents no control and 100, total control of plants [26].

Water samples for analysis of quality, pH and dissolved oxygen indicators were collected before and weekly after application (total of nine weeks), in all treatments, in the morning, always at the same time, between 8 and 09 H. The collection depth was performed between 15 - 20 cm below the water depth, and the samples were identified and stored in 500 mL plastic containers. The results were submitted to analysis of variance and Tukey test, considering a level of 5% of significance, using the statistical program Sisvar.

## 3. Results and Discussion

### 3.1. Efficiency of Glyphosate Control over Water Hyacinth

The data summarized in **Figure 1** show the mean percentage of glyphosate and freezing control level on water hyacinth (*Eichhornia crassipes*) in the assessments performed on the 7th, 14th, 21st, 28th, 35th and 64th Day After Application (DAA). The analysis of variance and Tukey test for the respective results are presented in **Table 1**.

The values found for freeze control show excellent control during all evaluations performed. Comparing with the control treatment with the herbicide, it was observed that there were no statistical differences from 21 DAA. However, it was observed that throughout the evaluated period, there was no total death of the plants, and in some tanks presented new sprouts of water hyacinth plants, causing the control efficiency to decrease from 28 DAA.

In the tanks where glyphosate herbicide was applied, the initial symptoms were yellowing of the leaves, followed by wilting and necrosis, with subsequent death of the plants.

According to the results obtained, glyphosate showed very good control over water hyacinth from 14 days after application (DAA), with average values of

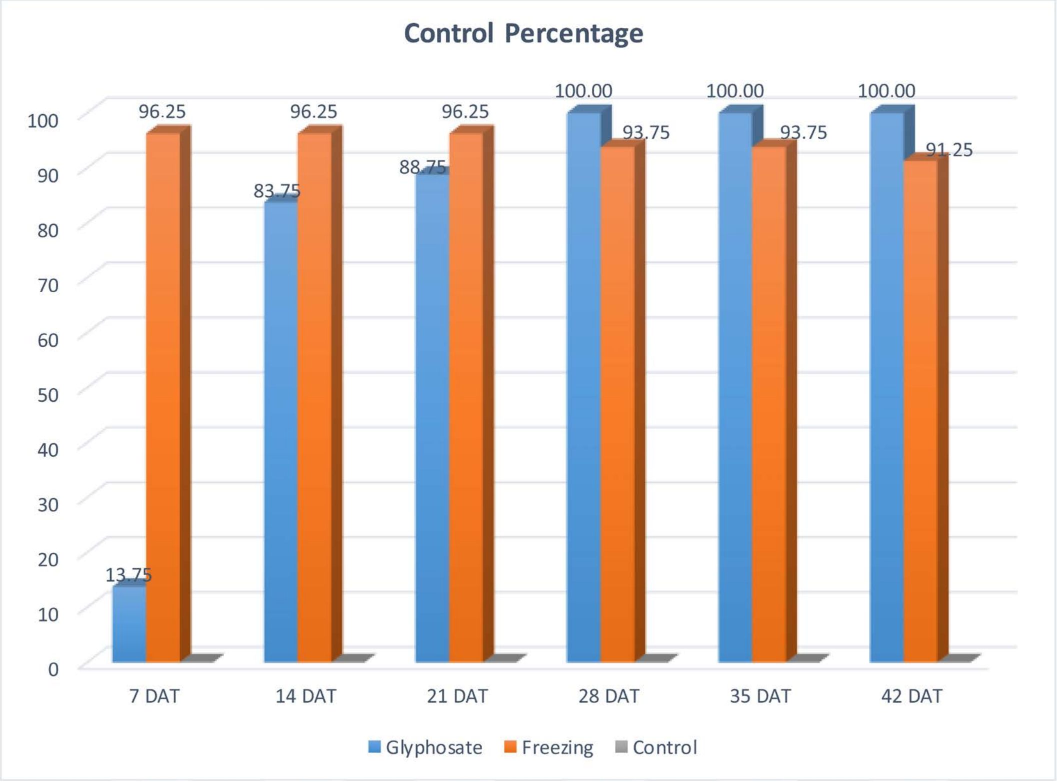


**Figure 1.** Percentage of glyphosate and freezing control over water hyacinth 7th, 14th, 21st, 28th, 35th and 64th Day After Application (DAA).

**Table 1.** Efficiency of glyphosate control over water hyacinth in reservoirs with plant and glyphosate application and with plant and control by freezing, at 7th, 14th, 21st, 28th, 35th and 42nd days after application.

| Treatments | Days After Treatment | | | | | |
|---|---|---|---|---|---|---|
| | 7 DAA | 14 DAA | 21 DAA | 28 DAA | 35 DAA | 42 DAA |
| 1 | 13.75bC | 83.75bB | 88.75aAB | 100.00aA | 100.00aA | 100.00aA |
| 2 | 96.25aA | 96.25aA | 96.25aA | 93.75aA | 93.75aA | 91.25aA |
| 3 | 0.00cD | 0.00cD | 0.00cD | 0.00cD | 0.00cD | 0.00cD |
| F Treatments | 1200.69 | 1213.62 | 786.14 | 669.44 | 406.09 | 263.69 |
| F Block | 3.08 | 3.08 | 1.14 | 1.00 | 1.00 | 1.00 |
| CV (%) | 8.19 | 5.01 | 6.19 | 6.70 | 8.61 | 10.70 |
| d.m.s. | 6.5163 | 6.5163 | 8.2821 | 9.391 | 11.9883 | 14.7934 |

Note. Averages followed by lowercase letters in the column and uppercase letters in the row do not differ from each other by the Tukey test at 5% probability. * Treatments: T1—With water hyacinth and glyphosate application; T2—With glyphosate and freezing control; T3—Witness (No plant and no control).

83.75%; evolving at 21 DAA to 88.75%. From 28 DAA until the last evaluation, at 42 DAA, the control was excellent reaching 100%. These data corroborate the control levels obtained by Cruz *et al.* [27], who, when evaluating the efficacy of glyphosate herbicide in water hyacinth control, found 100% control from 15 DAA. Similarly, Martins *et al.* [15] and Foloni *et al.* [16], performing chemical control of aquatic plants in water tanks, among them, water hyacinth, obtained excellent glyphosate weed control, respectively, at 20 days and 28 days after treatment.

Cardoso *et al.* [28], who studied the sensitivity of different hyacinth water accessions to herbicides collected in reservoirs of the State of São Paulo, found efficient control of water hyacinth plants for glyphosate herbicide, regardless of the genotype studied.

Other studies show the excellent efficacy of glyphosate herbicide in water hyacinth control [14] [17] [18] [29].

### 3.2. pH

The average values found of the water pH, with the respective statistical analyzes, in the different treatments in which the reservoirs were submitted, are expressed in **Table 2**.

As can be observed, treatments that were not colonized by water hyacinth presented similar pH values, without statistical differences, in all evaluated weeks. The results show that the glyphosate herbicide does not alter the ionic hydrogen potential of water and are in agreement with those found by Martins *et al.* [30], who evaluated the effects of water hyacinth management on water quality in mesocosms, found no differences for the pH parameter in the evaluated period. The results also corroborate with Guimarães, G.L. [31], Ahmed *et al.* [32], and Boyle, Terence P. [33] who, when evaluating the impact of macrophyte control using the 2.4D herbicide in mesocosm, found greater amplitudes of pH variations in mesocosms without macrophyte coverage.

**Table 2.** Mean pH values obtained before application and at 2, 4, 8, 16, 32 and 64 days after application in the five treatments evaluated.

| Treatments | WEEKS AFTER APPLICATION | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 1 | 6.45a | 6.10a | 6.14a | 6.10a | 5.87a | 5.60a | 5.66a | 5.33a | 5.15a | 4.37a |
| 2 | 6.86b | 6.67b | 6.76b | 6.76b | 6.81b | 6.84b | 6.99b | 7.05b | 7.13b | 6.79b |
| 3 | 6.89b | 6.74b | 6.97b | 6.91b | 6.88b | 6.76b | 6.91b | 6.81b | 6.90b | 7.51c |
| 4 | 8.22c | 8.32c | 8.32c | 9.12d | 9.20d | 9.24c | 8.91c | 8.61c | 8.86c | 8.28d |
| 5 | 8.17c | 8.00c | 8.02c | 8.49c | 8.84c | 9.05c | 9.01c | 8.67c | 8.40c | 8.39d |
| F Treatments | 140.93 | 193.49 | 67.65 | 98.60 | 486.02 | 169.41 | 140.49 | 295.91 | 108.55 | 404.36 |
| F Block | 2.86 | 0.03 | 1.76 | 0.11 | 0.41 | 1.53 | 0.73 | 1.30 | 2.31 | 2.62 |
| CV (%) | 1.890 | 1.900 | 3.050 | 3.420 | 1.730 | 3.240 | 3.240 | 2.220 | 3.830 | 2.310 |
| d.m.s. | 0.311 | 0.307 | 0.498 | 0.577 | 0.292 | 0.548 | 0.547 | 0.365 | 0.629 | 0.368 |

Note. Averages followed by a lowercase letter in the column do not differ from each other by the Tukey test at 5% probability. * Treatments: T1—With water hyacinth plants and no glyphosate application; T2—With water hyacinth and glyphosate application; T3—With water hyacinth plants and with freezing control; T4—Without water hyacinth plants and no glyphosate application; T5—Without water hyacinth plants and no glyphosate application.

According to Esteves, F.A. [34] cited by Martins *et al.* [30], algae present in water can raise the pH through $CO_2$ assimilation in the photosynthesis process.

On the other hand, all reservoirs colonized with water hyacinth showed lower statistical values than those without colonization. Martins *et al.* [30] comment that due to the large volume of water hyacinth roots, the respiratory activity is intense, causing the water pH to be reduced in its presence.

Treatments controlled by freezing or glyphosate herbicide did not differ statistically, showing that the type of control, whether chemical or physical, results in similar pH.

The treatment that contained the presence of water hyacinth without herbicide application had the lowest pH values. In the work [30] the same observation was obtained. The authors suggest that due to the intense respiratory activity of the root system in carbon dioxide production and the interception of sunlight prevented photosynthesis, causing pH values to decrease.

## 3.3. Dissolved Oxygen

The average values of dissolved oxygen ($mg \cdot L^{-1}$) of the water with the respective statistical analyses found in the different treatments in which the reservoirs were submitted are expressed in **Table 3**.

Throughout the experiment, reservoirs that were not colonized by water hyacinth had the highest values of dissolved oxygen and did not differ statistically from each other. Such observation is explained due to the absence of macrophyte coverage to facilitate oxygen diffusion processes at the water-atmosphere interface. Another factor in the water oxygenation process is algae that perform photosynthesis on the water column and increase the dissolved oxygen content

**Table 3.** Mean dissolved oxygen values ($mg \cdot L^{-1}$) obtained before application and at 2, 4, 8, 16, 32 and 64 days after application in the five treatments evaluated.

| Treatments | WEEKS AFTER APPLICATION | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 1 | 5.54b | 4.35c | 4.45b | 4.43b | 5.67b | 6.15c | 4.95c | 5.59b | 4.31b | 3.97b |
| 2 | 2.18a | 2.23a | 2.54a | 2.11a | 3.15a | 4.20b | 3.26b | 3.75a | 2.56a | 2.62a |
| 3 | 2.54a | 3.48b | 2.23a | 3.07a | 2.18a | 2.94a | 2.30a | 2.31a | 3.69ab | 2.27a |
| 4 | 8.50c | 8.86d | 9.47c | 8.67c | 8.44c | 8.23d | 8.36d | 9.22c | 7.62c | 8.40c |
| 5 | 8.49c | 8.29d | 8.30c | 8.04c | 8.88c | 8.70d | 8.58d | 8.98c | 7.47c | 8.45c |
| F Treatments | 124.73 | 260.43 | 113.86 | 159.58 | 130.87 | 392.15 | 199.44 | 80.31 | 39.21 | 352.31 |
| F Block | 0.28 | 0.30 | 0.27 | 3.97 | 0.30 | 0.42 | 1.06 | 2.12 | 0.78 | 3.28 |
| CV (%) | 10.090 | 6.750 | 11.540 | 8.860 | 9.330 | 4.170 | 7.430 | 11.540 | 14.260 | 6.350 |
| d.m.s. | 1.239 | 0.828 | 1.404 | 1.051 | 1.191 | 0.568 | 0.920 | 1.553 | 1.650 | 0.736 |

Note. Averages followed by a lowercase letter in the column do not differ from each other by the Tukey test at 5% probability. * Treatments: T1—With water hyacinth plants and no glyphosate application; T2—With water hyacinth and glyphosate application; T3—With water hyacinth plants and with freezing control; T4—Without water hyacinth plants and no glyphosate application; T5—Without water hyacinth plants and no glyphosate application.

in water [14].

Still in the reservoirs without macrophytes and without glyphosate application occurred fast algae development, contributing to the high dissolved oxygen values in the water. The same occurred with Martins *et al.* [30], who observed algae blooms in short periods of time. According to Schwegler, B.R. [35] cited by Martins *et al.* [30], the presence of algae in high concentrations can increase the dissolved oxygen content in water.

Reservoirs with freezing or herbicide control obtained very low values during the studied period. The results corroborate with Souza, E.L.C. [36] who, evaluating the environmental impact of glyphosate use in water hyacinth control, found low values for the dissolved oxygen parameter. According to Guimarães, G.L. [31] this fact can be explained by the increase in biochemical oxygen demand due to the process of death and degradation or decomposition of plants. As for reservoirs with plant and without control, the values were intermediate being between 4.3 and 6.2 $mg \cdot L^{-1}$.

The application of glyphosate in water without the presence of water hyacinth did not promote any significant reduction of dissolved oxygen levels in the water, during the entire observation period, when compared to the control, treatment without water hyacinth and without herbicide. The results corroborate with Souza, E.L.C. [36] who observed the same effect under the same conditions evaluated. Glyphosate application did not affect dissolved oxygen contents either by water dissipation [21] or glyphosate degradation by microbial activity [22] [23] [37] [38].

## 4. Conclusions

The use of glyphosate applied directly on the water surface or on plants or in the control of water hyacinth did not significantly alter the parameters of water quality, pH and dissolved oxygen analyzed.

The data obtained in the present experiment with the use of glyphosate herbicide at the evaluated dose showed excellent efficiency in the control of water hyacinth, in agreement with previous studies.

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## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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