

Period of rain after saflufenacil application in controlling floating aquatic macrophytes¹

Período de chuva após a aplicação de saflufenacil no controle de macrófitas aquáticas flutuantes

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Abstract - Saflufenacil herbicide can be one more alternative to control aquatic environment weeds, but at the time of or after the application of the herbicide bad weather such as rain, may invalidate the chemical control of problematic species occurring in this environment. Thus, the goal of this study was to evaluate the occurrence of different rain periods after applying saflufenacil herbicide to control water hyacinth and water lettuce plants. The study was conducted in plastic pots with 2.5 water liter capacity and kept in greenhouse conditions. The experimental design was completely randomized with nine treatments and four replications. Treatments consisted of rainfall simulation performed through a stationary sprayer in periods after the application of the herbicide: 0; 0.25; 0.5; 1; 2; 4; 6; and 12 hours, as well as a period without rain. Saflufenacil was applied at a 33.6 g ha⁻¹ dose and evaluations were performed 7, 14, 21, 28 and 35 days after herbicide application. The occurrence of rain at intervals of more than two hours after the application of saflufenacil did not change the effectiveness on water hyacinth. As for water lettuce plants, there was an effective control with a minimum of four hours for the occurrence of rain after application of the herbicide. Finally, for all plants, periods equal to or higher than six hours after the application of saflufenacil provided total control over water hyacinth and water lettuce plants.

Keywords: chemical control; *Eichhornia crassipes*; *Pistia stratiotes*

Resumo - O herbicida saflufenacil pode ser uma alternativa a mais para o controle de plantas daninhas de ambiente aquático, porém no momento ou após a aplicação do herbicida algumas intempéries, como a chuva, podem inviabilizar o controle químico de espécies problemáticas que ocorrem neste ambiente. Com isso, o objetivo deste trabalho foi avaliar a ocorrência de diferentes períodos de chuva após a aplicação do herbicida saflufenacil no controle de aguapé e alface d'água. O estudo foi instalado em vasos plásticos com capacidade de 2,5 litros de água e mantidos em casa de vegetação. O delineamento experimental utilizado foi o inteiramente casualizado com nove tratamentos e quatro repetições. Os tratamentos constaram da simulação de chuva realizada através de um pulverizado estacionário em períodos após a aplicação do herbicida: 0; 0,25; 0,5; 1; 2; 4; 6; e 12 horas, além do período sem chuva. O saflufenacil foi aplicado na dosagem de 33,6 g ha⁻¹ e foram realizadas avaliações aos 7, 14, 21, 28 e 35 dias após a aplicação do herbicida. Constatou-se que a ocorrência de chuva em intervalos superiores a duas horas após a aplicação do saflufenacil não alterou a eficiência no aguapé. Já para as plantas de alface d'água o controle foi eficiente com um tempo mínimo de quatro horas para a ocorrência de chuva após a aplicação deste herbicida.

¹ Received for publication on 19/07/2016 and approved on 08/10/2016.

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Finalmente, para todas as plantas, períodos iguais ou maiores que seis horas após a aplicação do saflufenacil proporcionam controle total das plantas de aguapé e alface d'água.

Palavras-chaves: controle químico; *Eichhornia crassipes*; *Pistia stratiotes*

Introduction

Floating aquatic weeds have caused a series of damages to the biological balance of the system and to man's activity, such as the obstruction of irrigation and drainage channels, damages to navigation, reduction of the capacity to generate electric power, among others (Vereecken et al., 2006; Martins et al., 2008; Martins et al., 2011).

Species of water hyacinth (*Eichhornia crassipes* (Mart.) Solms) and water lettuce (*Pistia stratiotes* L.) are constantly related in the most varied water environments, since they present great phenotypic plasticity and intense vegetative reproduction (Henry-Silva et al., 2008; Cancian et al., 2009; Martins et al., 2011).

Chemical control through the use of herbicides is the most used method to control these species, and it presents an elevated usage potential (Souza et al., 2011a; Campos et al., 2012; Kelly et al., 2012). However, the environment where these species occur may interfere in the absorption and translocation of herbicides, as well as the species foliar morphology, the herbicide characteristics and by the climate conditions during pulverization (Feng et al., 2000; Souza et al., 2011b; Campos et al., 2012; 2013).

Considering the possibility of using chemical control in water environments, saflufenacil may become an herbicide option to control species that are sensitive to it. Saflufenacil herbicide is an inhibitor of the protoporphyrinogen IX oxidase enzyme (PPO or PROTOX); it is used in post-emergence applications for a wide control of dicotyledonous weeds (Geier et al., 2009; Grossmann et al., 2010). Since it is an herbicide with low acute toxicity for human beings, fish, birds and insects (Knezevic et al., 2010), it may be a promising product to be used in water environments.

As for climate conditions, studies conducted to demonstrate the action of rain over the effectiveness of herbicides after their application during water plants post-emergence highlighted that they may cause a reduction in control effectiveness when they occur right after application, as well as climate conditions before application interfere in the effectiveness of herbicides (Anderson and Arnold, 1984; Souza et al., 2011b; Campos et al., 2012; Campos et al., 2013).

Since in literature there is no information referring to the minimum period of time without the occurrence of rain after the application of saflufenacil in controlling water weed species, it is necessary to conduct studies that may help making management decisions about these species. Therefore, this study had the goal of evaluating the influence of different rain periods occurred after the application of saflufenacil and its effectiveness in controlling water hyacinth and water lettuce plants.

Material and Methods

Water hyacinth and water lettuce plants, coming from a dam, were taken in 15x15x15 cm plastic trays, with 2.5 L water volumetric capacity, and were kept in a greenhouse; in each tray, there was one plant only.

The study was conducted in completely randomized design, with nine treatments and four replications, where tested treatments consisted in 10 mm rain simulation (5 minutes duration) in periods after the herbicide application: 0; 0.25; 0.5; 1; 2; 4; 6; and 12 hours, in addition to the period without rain. Saflufenacil (Heat, 700 g kg⁻¹ a.i., WG, BASF), was applied in the 33.6 g a.i. dose, and 0.5% v/v of Dash adjuvant was added to the mixture.

It is important to highlight that the period of 0 minutes for the rain simulation occurred immediately after saflufenacil pulverization

(not more than thirty seconds); this is the necessary time between the end of saflufenacil pulverization and the start of the rain simulation stationary system.

To apply the herbicide, a stationary pulverization system was used, air pressured and equipped with a 2L reservoir. The equipment was set to provide 200 L ha⁻¹ mixture consumption. The application bar was equipped with two XR 11002VS “Teejet” flat spray nozzles, spaced 50 cm apart. The environmental characteristics during application were: 25.5°C temperature and 73% relative air humidity.

Plants were visually evaluated on 7, 14, 21, 28, and 35 days after application (DAA), by a grade percentage scale, where zero represented no control and 100% total plant control, proposed by SBCPD (1995).

The obtained results were submitted to analysis of variance by F test; treatment averages were compared by Tukey’s test ($p < 0.05$).

Results and Discussion

In the study where the occurrence of rainfalls after the application of saflufenacil in controlling water hyacinth plants was evaluated, it is possible to observe that in all evaluated periods, there was a significant difference ($p < 0.05$) for the different periods without rain. At 7 DAA, it is possible to verify symptoms of phytotoxicity in water hyacinth plants during all evaluated rainfall periods after herbicide pulverization; however, the observed plant control was still not effective in none of the evaluated treatments (Table 1).

Table 1. Percentage of water hyacinth (*Eichhornia crassipes*) control after saflufenacil application under different intervals without rain. Botucatu (SP), 2013.

Periods without rain (hours)	7	14	21	28	35
	DAA				
0	10.5 b	17.5 e	28.0 de	41.8 d	46.8 d
0.25	12.0 b	15.0 e	15.8 e	18.8 e	23.8 e
0.5	15.8 b	28.3 cde	32.5 de	58.8 cd	63.8 cd
1	11.8 b	23.8 de	33.8 cd	70.0 bc	75.0 bc
2	15.0 b	45.0 cde	60.0 b	85.0 ab	90.0 ab
4	9.5 b	38.8 cd	49.5 bc	78.8 abc	83.8 abc
6	15.3 b	67.5 b	85.8 a	98.8 a	100.0 a
12	42.5 a	90.8 a	100.0 a	100.0 a	100.0 a
No rain	33.0 a	92.3 a	100.0 a	100.0 a	100.0 a
F	32.69 **	63.71 **	82.89 **	38.91 **	34.93 **
CV (%)	16.2	16.2	12.6	12.60	11.90
LSD	17.9	17.9	16.8	21.63	21.54

** Significant at 1% probability level. Averages followed by the same letter on the column do not statistically differ among themselves by Tukey’s test.

It is important to highlight that, already at 7 DAA, it was possible to verify that treatments with rain occurrence at zero minutes after saflufenacil application presented a negative impact on the appearance of visual symptoms on water hyacinth plants by the herbicide, since the biggest intoxication symptoms registered on these plants were more significant only when rain occurred from twelve hours on.

At 14 DAA, an increase in the control effectiveness of all tested treatments was registered. However, only the treatments with rain occurrence starting from twelve hours on after saflufenacil application and in the condition of rain absence presented satisfactory control of water hyacinth plants, with averages above 90% (Table 1).

In the evaluation performed at 21 DAA, it was also possible to verify that, despite the fact that a longer period of time was necessary

for an effective control, the occurrence of rain starting from six hours after saflufenacil application provided a high control of water hyacinth plants, with averages above 85% (Table 1). As for treatments with rain occurrence starting from twelve hours after saflufenacil application and in the condition of rain absence, total control of the plants was observed. On the other hand, the occurrence of rain in up to one hour after the application of saflufenacil drastically reduced the control effectiveness of this herbicide, providing less intoxication to water hyacinth plants.

At 28 DAA, elevated average control values of this water macrophyte were observed for treatments submitted to rainfall starting from two hours after the herbicide pulverization (Table 1). This is different from treatments with rain simulation immediately (zero minutes) after saflufenacil application, which presented a negative impact on its control effectiveness up to 41.25% for the occurrence of rain 30 minutes after application, compared to the treatment without rain.

Souza et al. (2011b) studies the occurrence of rain after the pulverization of glyphosate (Roundup Rodeo formula) in controlling water hyacinth plants, even if this an herbicide with a different mode of action; it was observed that the occurrence of rain immediately (0 hours) after the application of the herbicide negatively influenced its phytotoxic effect on water hyacinth plants. Researchers highlighted the need for a minimum interval of two hours between the application of the herbicide and the occurrence of rain in order to have an effective control over water hyacinth plants.

At the end of the study, at 35 DAA, it was evident that the occurrence of rainfalls between two and four hours after the application of saflufenacil obtained an efficient control, between 80 and 90% control over this species (Table 1). However, with the occurrence of rain six hours after the herbicide application, the control over water hyacinth plants was total, due

to a greater exposure of the plant to the herbicide, which allowed better absorption.

Yet, the control of water hyacinth by imazapyr and imazamox herbicides with 20 mm rainfall occurrence (five minutes) after the application of the herbicides, regardless of the period with no rain, did not affect the effectiveness of these herbicides (Campos et al., 2010; Campos et al., 2012). Souza et al. (2011a) also reported that diquat herbicide provided an excellent control over water hyacinth plants, regardless of the period of time for rain occurrence after its application.

Despite the fact that a greater period of time was necessary for a satisfactory control over water hyacinth plants when rainfall occurred right after its application, an effective control over plants was observed when rainfall occurred after a minimum period of two hours from the application of saflufenacil at the end of the study.

In the study with water lettuce plants, all periods without the occurrence of rainfall after the application of saflufenacil significantly differed in control ($p < 0.05$). At 7 DAA saflufenacil caused visual injuries to plants in all tested intervals without rain simulation (Table 2).

In the evaluation performed at 14 DAA, there is an increase in the visual symptoms caused by the application of saflufenacil, mainly for treatments with rain occurrence in the intervals of two, four, six and twelve hours after the application of this herbicide; the treatment without rain occurrence had satisfactory control, presenting values above 81% of water lettuce plant control (Table 2).

At 21 DAA, it is possible to observe that the application of saflufenacil provided levels of water lettuce plant control above 97%, when there was a minimum period of six hours without the occurrence of rain, similarly to the treatment without rain. However, it is important to highlight that with the occurrence of rainfalls four hours after the application of the herbicide, an effective control of these weeds may be observed, being higher than 83% (Table 2).

At 28 DAA, it was possible to observe that the occurrence of rainfalls four hours after the application of saflufenacil, the control over water lettuce plants was above 91%. As for the occurrence of rainfalls starting from six hours

after the herbicide application, the observed control over this very same species was 100%, indicating the maximum effectiveness of saflufenacil (Table 2).

Table 2. Percentage of water lettuce (*Pistia stratiotes*) control after saflufenacil application under different intervals without rain. Botucatu (SP), 2013.

Periods without rain (hours)	7	14	21	28	35
	DAA				
0	7.5 d	5.5 f	1.5 e	0.0 d	0.0 e
0.25	8.0 d	10.0 f	8.8 e	7.5 d	6.3 e
0.5	22.8 c	29.5 e	62.5 cd	47.5 c	37.5 d
1	30.5 ab	37.5 de	48.8 d	55.0 c	62.5 c
2	28.3 bc	44.5 cde	66.3 cd	78.8 b	85.0 b
4	36.3 a	67.5 ab	83.8 b	91.3 a	98.8 a
6	6.3 d	46.5 cde	97.0 ab	100.0 a	100.0 a
12	11.5 d	59.5 bc	97.0 ab	100.0 a	100.0 a
No rain	12.5 d	81.8 a	99.8 a	100.0 a	100.0 a
F	55.36 **	60.59 **	139.74 **	274.79 **	437.20 **
CV (%)	16.9	15.3	10.0	7.4	6.0
LSD	7.3	15.4	14.9	11.3	9.4

** Significant at 1% probability level. Averages followed by the same letter on the column do not statistically differ among themselves by Tukey's test.

It is important to highlight that the occurrence of rain in a maximum period of an hour reduced saflufenacil effectiveness by 45%. It is important to report that there was total saflufenacil effectiveness loss when rainfalls occurred immediately after pulverization, since water lettuce plants did not present any visual damage symptom (Table 2).

According to Campos et al. (2010), the occurrence of rain in up to six hours after the pulverization of imazapyr on *P. stratiotes* plants drastically reduced the effectiveness in controlling this herbicide. As for the pulverization of imazamox herbicide, a minimum time of eight hours was necessary to have a satisfactory control over water lettuce plants (Campos et al., 2012). This is different from the diquat herbicide, which provided an excellent control over these aquatic plants regardless the period for rain occurrence, even with the occurrence of rainfalls right after its application (Souza et al., 2011a).

At the end of the study, at 35 DAA, treatments where rain was simulated four or

more hours after the application of saflufenacil provided an excellent control over this aquatic plant. However, when rain occurred within a minimum interval of two hours, even if water lettuce plant control was considered good, it is possible to observe a reduction in the control effectiveness of this herbicide.

The results highlighted in this work, when compared to the ones in literature, support the hypothesis according to which the effectiveness of chemical control is related to the environmental conditions at the moment of pulverization. However, it may also be influenced by many other factors: different formula, herbicide and surfactant concentration, weed species and age, growth habits, foliar morphology and epicuticular wax composition (Kirkwood and McKay, 1994; Chachalis et al., 2001; Costa et al., 2006; Huangfu et al., 2007). It is important to highlight that the presence of trichomes on water lettuce or a great quantity of epicuticular wax on the foliar surface of water hyacinth plants may cause little adherence of pulverization drops, impeding their contact with

epidermis cells and reducing the effectiveness of herbicides, as observed in case of rain right after pulverization (Costa et al., 2006).

Saflufenacil has presented excellent effectiveness in controlling eudicot weeds; it may be used in combination with other herbicides, without affecting its effectiveness in controlling weeds and selectivity (Eubank et al., 2013; Gonçalves et al., 2016). It may be another tool for the management of weeds in aquatic environments. In order to use herbicides in new environments, it is necessary to conduct studies that prove their effectiveness, as well as the implications they may cause, in addition to knowledge about the characteristics of the product, such as half-life and degradation.

Conclusions

Saflufenacil herbicide was effective in controlling water hyacinth plants only when rainfalls occurred two hours after its application; for water lettuce plants, a period of four hours without rain was necessary for the herbicide to be effective.

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