Dose-response of morning-glory species to PPO inhibitors

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ABSTRACT

The objective of this research was to test the response of morning-glory species (*Ipomoea hederifolia* and *Ipomoea quamoclit*), two important weeds in Brazilian agricultural fields, growing after application of increased doses of carfentrazone-ethyl and saflufenacil. Pot dose-response tests were performed by spraying doses of carfentrazone-ethyl (0 up to 30 mL ai ha⁻¹) and saflufenacil (0 up to 35 g ai ha⁻¹) directly onto 6-8 leaved morning-glory plants. Dry mass accumulation was determined 14 days after spraying. At maximum field dose of carfentrazone-ethyl (30 mL ai ha⁻¹), dry mass reduced by 59% for *I. quamoclit* and 75% for *I. hederifolia*; for saflufenacil (35 g ai ha⁻¹), dry mass reduced by 83% for *I. quamoclit* and 71% for *I. hederifolia*. Both carfentrazone-ethyl and saflufenacil were very efficient to control *I. hederifolia* and *I. quamoclit*, since doses required to kill plants were very lower than recommended field doses (5.5% and 10% for carfentrazone-ethyl and saflufenacil, respectively, considering both species). Although *I. hederifolia* and *I. quamoclit* show a short different response to carfentrazone-ethyl and saflufenacil, both herbicides are efficient to control young plants in early post-emergence spraying.

Keywords: *Ipomoea hederifolia*, *Ipomoea quamoclit*, carfentrazone-ethyl, saflufenacil, dry mass.

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INTRODUCTION

Morning-glory species (*Ipomoea* spp.) commonly infest agricultural areas in Brazil (Kuva et al. 2008, Ferreira et al. 2011, Giancotti et al. 2014) where *Ipomoea hederifolia* and *Ipomoea quamoclit* have been two of the major weeds occurring in sugar cane, soybean, maize, and other crops. In addition to the direct interference on crops by competition for environmental resources, morning-glory weeds also indirectly interfere on the crop productivity by machinery blocking during mechanical harvesting (Carvalho et al. 2009, Carvalho et al. 2014).

To control morning-glory species, herbicides inhibiting the enzyme protoporphyrinogen oxidase (PPO) are been recommended for application mainly during the early plant development (MAPA 2014a,b). Carfentrazone-ethyl and saflufenacil are two PPO-inhibitor herbicides (HRAC 2014) recommended to control morning-glory species (MAPA 2014a,b), and the dose required for application is low for both herbicides. Thus, the use of inadequate doses may provide low efficacy of control or even increase the probability of weed resistance evolution. Although carfentrazone-ethyl has been used in the past years, saflufenacil is a herbicide of recent use in Brazil. In addition, we did not found any research in the literature comparing the dose-response of morning-glory plants to these both herbicides.

The objective was to test the response of *I. hederifolia* and *I. quamoclit* plants, regarding on dry mass accumulation, growing after application of increased doses of carfentrazone-ethyl and saflufenacil.

MATERIAL AND METHODS

Young plants of *I. hederifolia* and *I. quamoclit* grew during October and December 2013 in 5-L pots filled with a mixture of soil and organic substrate in a 4:1 proportion (v:v). Before sowing, 2 g of NPK (5-20-10) and 3 g of urea were applied. After sowing, plants were daily irrigated with 150 mL of water. Two plants grew in each pot and the pots were maintained under environmental conditions during the experiment (that are repeated twice).

Treatments consisted of the application of carfentrazone-ethyl (Aurora®, 400 g ai L⁻¹, FMC, Brazil), at doses of 0, 0.25, 0.5, 1, 2, 4, 5, 7.5, 10, 20, 35, 50, and 75 mL ha⁻¹ of the labeled herbicide, and saflufenacil (Heat®, 700 g ai L⁻¹, Basf, Brazil), at doses of 0, 0.125, 0.25, 0.5, 1, 2, 2.5, 5, 7.5, 10, 20, 35, and 50 g ha⁻¹ of the labeled herbicide, directly onto the shoot of *I. hederifolia* and *I. quamoclit* young plants (6-8 leaves). The experiment was performed in a 2x2x13 factorial scheme (2 species, 2 herbicides, and

13 doses for each herbicide), arranged in a completely randomized design with four replicates.

Herbicide was sprayed using a CO₂-pressurized sprayer with flat plan nozzles (TeeJet, 80.02, USA), pressure of 1.90 kgf cm⁻², and volume of application of 200 L ha⁻¹.

Fourteen days after herbicide application, plants were cut off close to soil and dried for 96 h in a forced air oven at 60 °C. After drying, plant material was weighted in an analytical balance (0,001 g) for dry mass determination.

Data were analyzed by regression, according to a non-linear, log-logistic model:

$$y = \min + (\max - \min) / [1 + (x^{\text{Hillslope}}/\text{EC50})]$$

where: y indicates the dry mass, min and max indicate the minimum and maximum value of dry mass, Hillslope is the slope of the curve, EC50 is the inflection point of the curve (representing the dose required to reduce the dry mass by 50%), and x indicates the dose of the herbicide.

Regression analysis was performed by using SigmaPlot® (Systat, version 10.0, USA). In addition, this software uses the Kolmogorov-Smirnov test to analyze the residual distribution and Spearman Rank correlation test between absolute values of residual and absolute values of dependent variable to check the constant variance.

RESULTS AND DISCUSSION

Dose-response to carfentrazone-ethyl. Young plants of *I. hederifolia* and *I. quamoclit* showed different response for dry mass accumulation at doses of carfentrazone-ethyl higher than 1.6 g ai ha⁻¹ (4 mL ha⁻¹ of the labeled herbicide – Figure 1). However, plants of both species died when exposed to doses equal or higher than that (data not shown), evidencing the efficacy of carfentrazone-ethyl to control 6-8 leaved morning-glory plants. Plants of *I. quamoclit* accumulated a little bit more dry mass than *I. hederifolia*, showing averagely 20% more dry mass accumulation at doses higher than 1.6 g ai ha⁻¹ (4 mL ha⁻¹ of the labeled herbicide). At field doses (50 up to 75 mL ha⁻¹ of the labeled herbicide), dry mass accumulation reduced by 55% and 59% for *I. quamoclit*, and 74% and 75% for *I. hederifolia*, respectively, evidencing that carfentrazone-ethyl was more efficient to reduce *I. hederifolia* plant growth, although plants of both species had died at field doses.

According to regression analysis (showing adjusted curves with high significance, residual with normal distribution, and constant variance), the labeled herbicide dose required to reduce the dry mass by 50% was 0.5 mL ha⁻¹ and 0.9 mL ha⁻¹ for *I. quamoclit* and *I. hederifolia*, respectively (Table 1). Those doses

Figure 1. Dose-response curves for *Ipomoea hederifolia* and *Ipomoea quamoclit* to carfentrazone-ethyl (Aurora®, 400 g ai L⁻¹, FMC, Brazil). Vertical lines indicate the standard error of the mean of four replicates.

Figure 2. Dose-response curves for *Ipomoea hederifolia* and *Ipomoea quamoclit* to saflufenacil (Heat®, 700 g ai kg⁻¹, Basf, Brazil). Vertical lines indicate the standard error of the mean of four replicates.

Table 1. Equation parameters and summarized results of statistical analysis used to estimate the dose-response of *Ipomoea quamoclit* (IQ) and *Ipomoea hederifolia* (IH) to carfentrazone-ethyl (Aurora®, 400 g ai L⁻¹, FMC, Brazil).

Species	Equation parameters ¹				ANOVA ²			CVT ³	NT ⁴
	min	max	EC50	Hillslope	R ²	F	P		
IQ	47.095	100.468	0.536	1.647	0.966	113.319	<0.001	0.761	0.591
IH	26.126	101.119	0.949	1.202	0.990	382.568	<0.001	0.864	0.069

¹ Regression equation: $y = \min + (\max - \min) / [1 + (x^{\text{Hillslope}} / \text{EC50})]$, where min is the minimum dry mass value, max is the maximum dry mass value, EC50 is the inflexion point of the curve (representing the dose required to reduce the dry mass by 50%), and Hillslope is the slope of the curve on EC50.

² ANOVA: R², F e P represent the adjusted coefficient of determination of the curve, F value, and P value (significance), respectively, for F test of the non-linear regression analysis.

³ CVT represents the significance (P value) of the constant variance test.

⁴ NT represents the significance (P value) of the residual normality test.

Table 2. Equation parameters and summarized results of statistical analysis used to estimate the dose-response of *Ipomoea quamoclit* (IQ) and *Ipomoea hederifolia* (IH) to saflufenacil (Heat®, 700 g ai kg⁻¹, Basf, Brazil).

Species	Equation parameters ¹				ANOVA ²			CVT ³	NT ⁴
	min	max	EC50	Hillslope	R ²	F	P		
IQ	20.232	100.606	1.704	1.512	0.993	577.187	<0.001	0.758	0.403
IH	31.281	101.263	0.607	0.988	0.988	336.423	<0.001	0.980	0.295

¹ Regression equation: $y = \min + (\max - \min) / [1 + (x^{\text{Hillslope}} / \text{EC50})]$, where min is the minimum dry mass value, max is the maximum dry mass value, EC50 is the inflexion point of the curve (representing the dose required to reduce the dry mass by 50%), and Hillslope is the slope of the curve on EC50.

² ANOVA: R², F e P represent the adjusted coefficient of determination of the curve, F value, and P value (significance), respectively, for F test of the non-linear regression analysis.

³ CVT represents the significance (P value) of the constant variance test.

⁴ NT represents the significance (P value) of the residual normality test.

were very low in relation to field doses, evidencing a high efficacy of carfentrazone-ethyl. In addition, at EC50, plants of *I. hederifolia* required doses 1.8 higher than *I. quamoclit* to show a similar dry mass reduction. However, as EC50 was too low and *I. quamoclit* plants accumulated less dry mass at doses higher than 4 mL ha⁻¹ of the labeled herbicide, we may infer that, in this case, analyzing the EC50(higher)/EC50(lower) quotient is not a good and adequate way to indicate which species is the most or the least susceptible to carfentrazone-ethyl, but we may infer that both of them were very susceptible to this herbicide.

Carfentrazone-ethyl is a PPO inhibitor from the triazolinone group (HRAC 2014) that is recommended

for post-emergence spraying aiming to control annual broad-leaved weeds and some annual narrow-leaved weeds during initial growth stages (MAPA 2014). Admittedly as a contact herbicide with insignificant translocation and whose mode of action depends on the sunlight, carfentrazone-ethyl penetrates the leaf and diffuses into epidermal cells mainly through cuticular polar ways, being absorbed through the plasmalemma into the chloroplasts where PPO is inhibited. As a consequence, the synthesis of protoporphyrin IX (precursor of cytochromes and α -chlorophylls) is blocked in the chloroplast. Accumulated protoporphyrinogen IX (not converted into protoporphyrin IX in the chloroplast) migrates to the

cytoplasm where is converted to protoporphyrin IX that is oxidized in the presence of light. As a consequence, singlet oxygen and other free radicals are formed, causing peroxidation of lipids, destruction of membranes, death of cells, and, for susceptible species, death of plants in a few days (Merotto Jr and Vidal 2001).

Thus, results allow us to infer that plants of *I. hederifolia* suffered toxic effects of carfentrazone-ethyl (at doses from 4 mL ha⁻¹ of the labeled herbicide) earlier and more intensively than *I. quamoclit*, although the herbicide had been efficient to kill both species.

Dose-response to saflufenacil. Young plants of *I. hederifolia* and *I. quamoclit* showed different response for dry mass accumulation at doses of saflufenacil higher than 3.5 g ai ha⁻¹ (5 g ha⁻¹ of the labeled herbicide – Figure 2). However, plants of both species died when exposed to doses equal or higher than that (data not shown), evidencing the efficacy of saflufenacil to control 6-8 leaved morning-glory plants. Plants of *I. hederifolia* accumulated a little bit more dry mass than *I. quamoclit*, showing averagely 10% more dry mass accumulation at doses higher than 3.5 g ai ha⁻¹ (5 g ha⁻¹ of the labeled herbicide). At field doses (35 up to 50 g ha⁻¹ of the labeled herbicide), dry mass accumulation reduced by 80% and 83% for *I. quamoclit*, and 68% and 71% for *I. hederifolia*, respectively, evidencing that saflufenacil was more efficient to reduce *I. quamoclit* plant growth, although plants of both species had died at field doses.

According to regression analysis (showing adjusted curves with high significance, residual with normal distribution, and constant variance), the labeled herbicide dose required to reduce the dry mass by 50% was 0.6 g ha⁻¹ and 1.7 g ha⁻¹ for *I. hederifolia* and *I. quamoclit*, respectively (Table 2). Those doses were very low in relation to field doses, evidencing a high efficacy of saflufenacil. In addition, at EC50, plants of *I. quamoclit* required doses 2.8 higher than *I. hederifolia* to show a similar dry mass reduction. However, as EC50 was too low and *I. hederifolia* plants accumulated less dry mass at doses higher than 5 g ha⁻¹ of the labeled herbicide, we may infer that, in this case, analyzing the EC50(higher)/EC50(lower) quotient is not also a good and adequate way to indicate which species is the most or the least susceptible to saflufenacil, but we may infer that both of them were very susceptible to this herbicide.

Characteristics and the mode of action of the herbicide saflufenacil are very similar to carfentrazone-ethyl, as described above.

Thus, results allow us to infer that plants of *I. quamoclit* suffered toxic effects of saflufenacil (at doses from 5 g ha⁻¹ of the labeled herbicide) earlier

and more intensively than *I. hederifolia*, although the herbicide had been efficient to kill both species.

Final consideration. Both carfentrazone-ethyl and saflufenacil were very efficient to control *I. hederifolia* and *I. quamoclit*, since doses required to kill plants were very lower than recommended field doses, as discussed above. In addition, doses required to reduce dry mass by 50% were lower than 3% and 3.5% for carfentrazone-ethyl and saflufenacil, respectively, for both species. So, these results evidence the high efficacy of those herbicides. The efficacy of carfentrazone-ethyl to control morning-glory species was observed by Christoffoleti et al. (2006) who concluded that dose of 10 g ha⁻¹ was sufficient to a satisfactory control (80%) and the dose of 50 g ha⁻¹ was required for 100% of control. The efficacy of carfentrazone-ethyl to control morning-glory species was also verified by Sharma and Singh (2007). For saflufenacil, we did not found any specific paper on the herbicide efficacy, but some authors reported an excellent control of morning-glory species by using this herbicide in works published in annals of scientific events (Foloni et al. 2009, Fornaroli et al. 2010, Carvalho et al. 2012). So, we may infer that carfentrazone-ethyl and saflufenacil were very efficient herbicides to control *I. hederifolia* and *I. quamoclit* when sprayed onto 6-8 leaved morning-glory plants.

CONCLUSION

Carfentrazone-ethyl and saflufenacil are efficient herbicides to control *I. hederifolia* and *I. quamoclit* young plants in post-emergence spraying, killing 6-8 leaved plants at doses lower than 5% of the field doses. Young plants of *I. hederifolia* and *I. quamoclit* show a different dry mass accumulation after being exposed to carfentrazone-ethyl and saflufenacil, however carfentrazone-ethyl is a little bit more efficient to control *I. hederifolia* plants and saflufenacil is a little bit more efficient to control *I. quamoclit* plants.

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References

- Carvalho LB, Bianco S, Pitelli RA. 2009. Growth and mineral nutrition of *Ipomoea quamoclit*. *Planta Daninha* 27: 283–288.
- Carvalho FT, Zambon S, Pereira FAR. 2012. Seletividade e eficácia do herbicida saflufenacil na cultura do milho. In: Anais do XXIX Congresso Brasileiro da Ciência das Plantas Daninhas. Gramado: SBCPD. CD-Rom.
- Carvalho LB, Bianco S, Bianco MS. 2014. Estudo comparativo do acúmulo de massa seca e macronutrientes por plantas de *Zea mays* e *Ipomoea hederifolia*. *Planta Daninha* 32: 99–107.

- Christoffoleti PJ, Borges A, Nicolai M, Carvalho SJP, López-Ovejero RF, Monquero PA. 2006. Carfentrazone-ethyl aplicado em pós-emergência para o controle de *Ipomoea* spp. e *Commelina benghalensis* na cultura da cana-de-açúcar. *Planta Daninha* 24: 83–90.
- Ferreira RV, Contato ED, Kuva MA, Ferraudo AS, Alves PLCA, Magario FB, Salgado TP. 2011. Organização das comunidades infestantes de plantas daninhas na cultura da cana-de-açúcar em agrupamentos-padrão. *Planta Daninha* 29: 363–371.
- Foloni LL, Souza ELC, Zambon S. 2009. Eficácia do saflufenacil em aplicação de pré-colheita de cana-de-açúcar visando o controle de *Ipomoea quamoclit* e *Ipomoea grandifolia* em colheita mecanizada. In: Anales del XII Congreso de la SEMh/XIX Congreso de la ALAM/II Congreso de la IBCM. Lisboa: SEMh/ALAM/IBCM. pp.747–750.
- Fornarolli DA, Nietzsche JF, Nietzsche FF, Basaglia A. 2010. Eficácia do herbicida Kixor no controle das espécies *Ipomoea triloba* e *Bidens pilosa* na região de Campo Mourão. In: Anais do XXVII Congresso Brasileiro da Ciência das Plantas Daninhas. Ribeirão Preto: SBPCD. pp.22–25.
- Giancotti PRF, Toledo REB, Alves PLCA, Victoria Filho R, Cason JB, Rocha MG. 2014. Chemical control of morning glory as a function of water restriction levels. *Planta Daninha* 32: 345–353.
- HRAC – Herbicide Resistance Action Committee. The world of herbicides. HRAC, 2010. <<http://www.hracglobal.com>>.
- MAPA - Ministério da Agricultura Pecuária e Abastecimento do Brasil. 2014a. Sistema de Agrotóxicos Fitossanitários. Carfentrazone-ethyl. Ministério da Agricultura Pecuária e Abastecimento, Brasil. <<http://agrofit.agricultura.gov.br>>.
- MAPA - Ministério da Agricultura Pecuária e Abastecimento do Brasil. 2014b. Sistema de Agrotóxicos Fitossanitários. Saflufenacil. Ministério da Agricultura Pecuária e Abastecimento, Brasil. <<http://agrofit.agricultura.gov.br>>.
- Merotto Jr A, Vidal RA. 2001. Herbicidas inibidores da PROTOX. In: Vidal RA, Merotto Jr A. *Herbicidologia*. Porto Alegre: Edição dos autores. pp.69–86.
- Sharma, SD, Singh M. 2007. Effect of timing and rates of application of glyphosate and carfentrazone herbicides and their mixtures on the control of some broadleaf weeds. *HortSci* 42: 1221–1226.

RESUMO

Dose-resposta de espécies de corda-de-violão a inibidores de PPO. O objetivo desta pesquisa foi testar a resposta de espécies de corda-de-violão (*Ipomoea hederifolia* e *Ipomoea quamoclit*), duas importantes plantas daninhas em campos agrícolas brasileiros, crescendo após a aplicação de doses crescentes de carfentrazone-ethyl (0 a 30 mL ia ha⁻¹) e saflufenacil (0 a 35 g ia ha⁻¹) diretamente sobre plantas de corda-de-violão com 6-8 folhas. O acúmulo de massa seca foi determinado aos 14 dias após a aplicação. Na máxima dose de campo de carfentrazone-ethyl (30 mL ia ha⁻¹), a massa seca foi reduzida em 59% para *I. quamoclit* e 75% para *I. hederifolia*; para saflufenacil (35 g ia ha⁻¹), a massa seca foi reduzida em 83% para *I. quamoclit* e 71% para *I. hederifolia*. Ambos carfentrazone-ethyl e saflufenacil foram eficazes para controlar *I. hederifolia* e *I. quamoclit*, uma vez que as doses requeridas para matar as plantas foram muito mais baixas que as doses de campo recomendadas (5,5% e 10% para carfentrazone-ethyl e saflufenacil, respectivamente, considerando ambas as espécies). Embora *I. hederifolia* e *I. quamoclit* apresentem pequena diferença na resposta a carfentrazone-ethyl e saflufenacil, ambos os herbicidas são eficazes para controlar plantas jovens em aplicação em pós-emergência precoce.

Palavras-chave: *Ipomoea hederifolia*, *Ipomoea quamoclit*, carfentrazone-ethyl, saflufenacil, massa seca.

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