

Efficacy and interaction of dicamba-haloxyfop tank mixtures

Interação e eficácia de mistura em tanque dos herbicidas dicamba e haloxyfop

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ABSTRACT

The application of herbicide tank mixtures is a common practice in agricultural settings, especially for controlling weed communities with mono and eudicotyledons species occurring simultaneously. Therefore, this study was carried out with the objective of evaluating the effectiveness and interaction of dicamba-haloxyfop tank mixtures used to control four weed species. For this, four different experiments were conducted, each with one of the plant species, namely: sourgrass (*Digitaria insularis*), horseweed (*Conyza* spp.), morning glory (*Ipomoea triloba*) and goosegrass (*Eleusine indica*). In each experiment, the experimental design consisted of completely randomized blocks, in a 4x4 factorial scheme of treatments, totaling 16 treatments with five replications, i.e., 80 plots of each species. Four doses of the herbicide dicamba (480, 240, 120 and 0 g ha⁻¹) and four doses of the herbicide haloxyfop (60, 30, 15 and 0 g ha⁻¹) were adopted. Percentage control was evaluated at 14 and 28 days after application (DAA) and mass of dry matter was evaluated at 28 DAA. Antagonistic, additive and synergistic effects were observed for dicamba-haloxyfop tank mixtures, with a greater preponderance of additive effects. Considering all four plant species, in different doses and dates of evaluation, 72 dicamba-haloxyfop interactions were evaluated, in which 50 were considered additives. However, the possibility of antagonism (9 interactions) or even synergy (13 interactions) cannot be ruled out, subjected to the influence of the herbicide dose, plant species and moment of evaluation.

KEYWORDS: ACCase inhibitors, auxinic herbicides, synergy, antagonism, additivity.

RESUMO

A aplicação de misturas de herbicidas é uma prática recorrente no ambiente agrícola, sobretudo para controle de comunidades mistas de plantas daninhas, quando há ocorrência simultânea de espécies mono e eudicotiledôneas. Assim sendo, este trabalho foi realizado com o objetivo de avaliar a eficácia e a interação de misturas dos herbicidas haloxyfop (graminocida) e dicamba (latifolicida) para controle de quatro espécies de plantas daninhas. Para tanto, quatro experimentos distintos foram realizados, cada um com uma espécie vegetal, a saber: capim-amargoso (*Digitaria insularis*), buva (*Conyza* spp.), corda-de-viola (*Ipomoea triloba*) e capim-pé-de-galinha (*Eleusine indica*). Em cada experimento, foi adotado modelo experimental de blocos ao acaso, no esquema fatorial 4x4, totalizando 16 tratamentos e cinco repetições, ou seja, 80 parcelas de cada espécie. Foram utilizadas quatro doses do herbicida dicamba (480, 240, 120 e 0 g ha⁻¹) e quatro doses do herbicida haloxyfop (60, 30, 15 e 0 g ha⁻¹). Foi avaliado o controle percentual das parcelas aos 14 e 28 dias após aplicação (DAA) e massa seca residual aos 28 DAA. Foram observados efeitos antagônicos, aditivos e sinérgicos para misturas entre dicamba e haloxyfop, com maior preponderância de efeitos aditivos. Considerando-se todas as quatro espécies vegetais, em diferentes doses e datas de avaliação, foram avaliadas 72 misturas de dicamba e haloxyfop, em que 50 destas foram consideradas aditivas. Porém, não se pode descartar a possibilidade de antagonismo (nove interações) ou mesmo sinergia (13 interações), sob influência da dose do herbicida, espécie vegetal e momento de avaliação.

PALAVRAS-CHAVE: ACCase, herbicidas auxínicos, sinergia, antagonismo, aditividade.

INTRODUCTION

Continuous technological investments have paved the road to development of modern agriculture, enabling the industry to reach high levels of productivity. However, several biotic factors still negatively

interfere with crops, with emphasis on weeds, which are a major concern in agriculture (VASCONCELOS et al. 2012). The infestation of weeds in agricultural areas promote qualitative and quantitative reduction in production. These plants interfere in the development of crops by competing for growth resources such as nutrients, light and water, which compromise the basis for crop productivity. In addition, these plants are hosts for pests and diseases, and interfere with harvest procedures (CARVALHO & CHRISTOFFOLETI 2008, SILVA et al. 2014).

Chemical control with herbicides is the most effective and economically viable method to solve the problem of weeds, especially in large cropping areas (AGOSTINETTO et al. 2009, CIUBERKIS et al. 2010). However, some species such as sourgrass (*Digitaria insularis*), goosegrass (*Eleusine indica*) and horseweed (*Conyza* spp.) still remain highly important in agriculture due to the selection of biotypes resistant to the main recommended herbicide, glyphosate (LICORINI et al. 2015, DALAZEN et al. 2019, HEAP 2019).

The problem with weeds may also be aggravated as a result of mixed infestations, i.e., plant communities composed of mono and eudicotyledons species occurring simultaneously. For example, chemical control becomes much more complex when sourgrass or goosegrass is present in the same agricultural area of glyphosate-resistant horseweed or tolerant broad-leaved plants, such as pigweed and benghal dayflower (LEAL 2018).

In this case, using mixtures of herbicides is the main alternative to minimize the problems attributed to hard-to-kill weeds and herbicide-resistant biotypes. However, the molecules mixed together must be effective in controlling these species. Herbicide tank mixtures should contribute to improve the efficacy of management as well as provide a broad spectrum of control (GAZZIERO 2015, ANDRADE et al. 2018, CARVALHO et al. 2019). The mixture of two or more herbicides contributes to a most efficient system of production when compared to sequential application of herbicides (SCHERDER et al. 2005).

Another strategy that may contribute to chemical control of weeds is the introduction of herbicide-tolerant crops, with emphasis on dicamba-tolerant soybeans, scheduled to be launched in the coming years. In this way, this herbicide becomes an option for broadleaf weed management in Brazil, such as horseweeds commonly found in soybean crops. Considering several cases involving glyphosate-resistant horseweed, as well as its resistance to other modes of action, dicamba has become very useful in agriculture, being an alternative for management of the *Conyza* genus, by itself or in a mixture with other herbicides (SOARES et al. 2012, OSIPE 2015).

Using herbicide tank mixtures or successive application of herbicides with different modes of action also contribute to reduce selection pressure for the emergence of new herbicide-resistant biotypes, thus its importance as a tool for weed management in agriculture (ALONSO et al. 2013). When a mixture of herbicides is made, three possible effects may be observed. If the control obtained from the association of herbicides is greater than the sum of the herbicide's isolated effects, then a synergistic mixture is obtained; if the control obtained with the mixture is lower than the expected value of the sum of the isolated effects, then the mixture is antagonistic; and when there is no difference, it is considered to be an additive mixture (COLBY 1967, GAZZIERO 2015, ANDRADE et al. 2018).

Frequently, the use of mixtures does not provide a satisfactory effect due to the antagonism of the molecules, therefore studies are important for evaluating different combinations of herbicides, with emphasis on the combination of latifolicides and graminicides, in order to propose new alternatives for the concomitant control of narrow and broad-leaf weed species in agricultural cropping areas. Thus, this study was carried out with the objective of evaluating the effectiveness and interaction of dicamba-haloxyfop tank mixtures in order to control four different weed species.

MATERIAL AND METHODS

Four similar experiments were carried out in a greenhouse at the Federal Institute of Education, Science and Technology of the South of Minas Gerais, Campus Machado, MG (21° 40 'S, 45° 55' W, 850 m of altitude), in the municipality of Machado in the state of Minas Gerais, Brazil. Different dicamba-haloxyfop mixtures were evaluated on four weed species. Two monocotyledons and two eudicotyledons species were used in order to enable analysis of the mixture's effect on the graminicide and latifolicide activity. Thus, between September and December 2018, herbicidal effectiveness was evaluated on sourgrass (*Digitaria insularis*) and horseweed (*Conyza* spp.). Between March and May 2019, the effectiveness on morning glory (*Ipomoea triloba*) was studied; and between July and October 2019, goosegrass (*Eleusine indica*) was evaluated.

Initially, weed seeds were distributed in 2 L-plastic trays, filled with commercial substrate, and later taken to the greenhouse with automated irrigation in order to promote germination. After seedling

emergence, at the phenological stage of a fully expanded leaf (monocotyledons) or the presence of cotyledonary leaves (eudicotyledons), the seedlings were transplanted into pots where they remained until the end of the experiments, with an average of three (morning glory) or five plants per pot (horseweed, sourgrass and goosegrass). Each plot consisted of a 1L-plastic pot filled with a mixture of commercial substrate, disaggregated sieved clay soil, manure and vermiculite in the proportion of 4:2:1:1 v/v, properly fertilized.

Experiments followed the experimental model of completely randomized blocks, and treatments were organized according to a 4x4 factorial scheme, totaling 16 treatments with five replications, i.e., 80 plots of each species. For each experiment, four doses of the herbicide dicamba (480, 240, 120 and 0 g ha⁻¹) and four doses of the herbicide haloxyfop (60, 30, 15 and 0 g ha⁻¹) were combined. Spray solutions were prepared in laboratory with deionized water to avoid contamination, and Assist[®] mineral oil was included in all the treatments, 0.4% v/v.

Applications were performed on plants at the phenological stage of tillering (sourgrass and goosegrass), with four leaves (morning glory) or six completely expanded leaves (horseweed). For this purpose, a CO₂-pressurized backpack sprayer was used, coupled to a single TeeJet TTI 110.02 nozzle, placed 0.50 m above the targets, with a relative spray consumption proportional to 200 L ha⁻¹.

Percentage control evaluations were performed at 14 and 28 days after application (DAA). For these evaluations, the method proposed by the Brazilian Weed Science Society was adopted (VELINI et al. 1995), which suggests a percentage scale variable between zero and 100%, in which 0% was attributed to plants with no symptoms, and 100% for absolute control, that is, the death of the plants. Mass of dry matter was obtained collecting the remaining plant material in the plots at 28 DAA, this material was dried in an oven with air-forced circulation, at 70°C, for 72 hours, and furtherly weighted.

Data were analyzed by applying the F-test on variance analysis, followed by Scott-Knott's test (SCOTT & KNOTT 1974), both with 5% of significance (Sisvar software, v.5.0). If only one level of treatments is considered, quantitative treatments are observed. However, to enable antagonism-synergism mixture analysis, regressions were not performed.

Analysis of antagonism-synergism was based on Colby's method (COLBY 1967):

$$E = 100 - \frac{(100 - X) * (100 - Y)}{100}$$

Where: X is the percent of control reached by dicamba at the rate of x; Y is the percent control of reached by haloxyfop at the rate of y; and E is the expected percent of control of dicamba-haloxyfop mixtures in the same rates (x + y) (ANDRADE et al. 2018, CARVALHO et al. 2019).

Then, E shall be considered as the mixture's expected toxicity. If the observed response is higher than expected, the mixture is considered synergistic; if the observed response is lower than expected, the mixture is antagonistic; if the observed and expected responses are equal, than the mixture is additive. For comparing expected and observed responses, the LSD test was adopted, also with 5% of significance.

RESULTS AND DISCUSSION

Evaluation of mixture effectiveness on monocots achieved similar results between species (Tables 1 and 2). No factorial interaction effect was detected for any variable evaluated for sourgrass or goosegrass, in which the herbicide haloxyfop had evident and constant effect. Haloxyfop ensured full control of these species at the dose of 60 g ha⁻¹, reaching 99.9% effectiveness on sourgrass and 98.1% on goosegrass, at 28 DAA. In this evaluation, results were stabilized and only the effects of haloxyfop in different doses was evident, in which using this molecule guaranteed species control. Analysis of mass of dry matter is congruent with control data, denoting the effectiveness of the herbicide haloxyfop (Tables 1 and 2).

In all monocots control evaluations, herbicide dicamba applied alone on the plants did not cause satisfactory control, in any dosage, which was expected, since this product is recommended only for controlling broadleaf weeds. In the evaluation of dry matter at 28 DAA, no mixture interaction was identified, which evidences only the effect of the herbicide haloxyfop (Tables 1 and 2).

Grass tolerance to auxinic herbicides (dicamba) is probably due to the limitation of herbicide translocation by the phloem related to the presence of typical anatomical structures such as nodes and intercalary meristem (OLIVEIRA Jr. 2011). Most growth-regulating herbicides are readily absorbed by both roots and leaves, and translocated by both phloem and xylem. However, translocation of these herbicides in grass leaves is more restricted than in susceptible broad leaves. Thus, these herbicides are used primarily to control broadleaf weeds (PETERSON et al. 2001).

Table 1. Percentage control¹ of sourgrass (*Digitaria insularis*) evaluated at 14 and 28 DAA² and mass of dry matter evaluated at 28 DAA, after spraying different doses of the herbicides dicamba and haloxyfop, isolated or in mixture. Machado, MG, Brazil, 2018.

Dicamba (g ha ⁻¹)	Haloxyfop ¹ (g ha ⁻¹)				Mean
	0	15	30	60	
Control evaluation performed at 14 DAA ²					
0	0.0	46.0	47.0	69.0	40.5 B
120	0.0	48.6	69.0	72.0	47.4 A
240	0.0	53.0	69.0	79.0	50.3 A
480	0.0	52.6	74.0	83.0	52.4 A
Mean	0.0 d	50.1 c	64.8 b	75.8 a	---
	CV = 18.53	F _{int} = 1.935 ^{ns}	F _{dic} = 6.892*	F _{hlf} = 287.481*	
Control evaluation performed at 28 DAA ²					
0	0.0	96.2	98.6	99.8	73.7
120	0.0	89.0	100.0	99.8	72.2
240	0.0	94.4	99.6	100.0	73.5
480	0.0	91.4	100.0	99.8	72.8
Mean	0.0 b	92.8 a	99.9 a	99.9 a	---
	CV = 5.19	F _{int} = 1.023 ^{ns}	F _{dic} = 0.625 ^{ns}	F _{hlf} = 3,313.376*	
Mass of Dry Matter ³ (g plot ⁻¹) evaluated at 28 DAA ²					
0	6.78	1.43	1.83	1.33	2.85
120	5.24	1.54	1.25	1.00	2.26
240	5.87	1.52	1.46	1.45	2.58
480	6.13	1.32	1.01	1.11	2.39
Mean	6.01 b	1.45 a	1.39 a	1.22 a	---
	CV = 15.19	F _{int} = 0.346 ^{ns}	F _{dic} = 1.087 ^{ns}	F _{hlf} = 75.773*	

¹Means followed by the same letter, uppercase in the columns and lowercase in the rows, do not differ according to Scott-Knott's test, with 5% of significance; ²DAA - days after application; ³Original data presented, previously transformed by $\sqrt{x+1}$; * Significant at the F test, with 1% of significance; ^{ns}F test not significant.

Table 2. Percentage control¹ of goosegrass (*Eleusine indica*) evaluated at 14 and 28 DAA² and mass of dry matter evaluated at 28 DAA, after spraying different doses of the herbicides dicamba and haloxyfop, isolated or in mixture. Machado, MG, Brazil, 2019.

Dicamba (g ha ⁻¹)	Haloxyfop ¹ (g ha ⁻¹)				Mean
	0	15	30	60	
Control evaluation performed at 14 DAA ²					
0	0.0	45.6	67.4	80.8	45.5
120	8.0	42.4	66.4	71.0	46.9
240	23.0	55.0	61.0	67.0	51.5
480	8.2	49.0	49.6	68.0	43.7
Mean	9.8 d	48.0 c	61.1 b	71.7 a	---
	CV = 26.03	F _{int} = 2.01 ^{ns}	F _{dic} = 1.37 ^{ns}	F _{hlf} = 95.00*	
Control evaluation performed at 28 DAA ²					
0	0.0	69.0	95.4	100.0	66.1
120	0.0	58.0	98.8	95.4	63.1
240	0.0	76.2	88.0	99.2	65.9
480	0.0	75.0	77.0	97.6	62.4
Mean	0.0 c	69.6 b	89.8 a	98.1 a	---
	CV = 20.67	F _{int} = 1.432 ^{ns}	F _{dic} = 0.407 ^{ns}	F _{hlf} = 224.227*	
Mass of Dry Matter ³ (g plot ⁻¹) evaluated at 28 DAA ²					
0	7.86	1.71	1.21	1.02	2.95
120	6.96	2.65	1.12	1.34	3.02
240	4.81	1.56	1.92	1.14	2.36
480	7.86	2.16	1.76	1.35	3.28
Mean	6.87 b	2.02 a	1.50 a	1.21 a	---
	CV = 18.78	F _{int} = 1.130 ^{ns}	F _{dic} = 1.403 ^{ns}	F _{hlf} = 57.064*	

¹Means followed by the same letter, uppercase in the columns and lowercase in the rows, do not differ according to Scott-Knott's test, with 5% of significance; ²DAA - days after application; ³Original data presented, previously transformed by $\sqrt{x+1}$; * Significant at the F test, with 1% of significance; ^{ns}F test not significant.

Still considering monocotyledonous species, mixture analysis by Colby's method (COLBY 1967) is detailed in Table 3. Two antagonistic interactions, four synergistic and 12 additive interactions were found for sourgrass, considering accumulated evaluations performed at 14 and 28 DAA. For goosegrass, three antagonistic interactions and 15 additive interactions were identified. It was not possible to assume a pattern of interactions, related to the dose of the products or evaluation moments. In general, the occurrence of additive effects was predominant, which suggests this result is more common in monocotyledons, possibly resulting from the adjuvants present in the formulations that contributed to the effectiveness of graminicide, since dicamba has no relevant effect on grasses.

Table 3. Interaction analysis of dicamba-haloxyfop tank mixtures at 14 and 28 days after application (DAA) on sourgrass (*Digitaria insularis*) and goosegrass (*Eleusine indica*). Machado, MG, Brazil, 2018/19.

Dicamba (g ha ⁻¹)	Haloxyfop (g ha ⁻¹)								
	15			30			60		
	Obs. ¹	Exp. ²	Int. ³	Obs. ¹	Exp. ²	Int. ³	Obs. ¹	Exp. ²	Int. ³
Sourgrass - 14 DAA - LSD _t = 11.16									
120	48.6	46.0	=	69.0	47.0	+	72.0	69.0	=
240	53.0	46.0	=	69.0	47.0	+	79.0	69.0	=
480	52.6	46.0	=	74.0	47.0	+	83.0	69.0	+
Sourgrass - 28 DAA - LSD _t = 4.79									
120	89.0	96.2	-	100.0	98.6	=	99.8	99.8	=
240	94.4	96.2	=	99.6	98.6	=	100.0	99.8	=
480	91.4	96.2	-	100.0	98.6	=	99.8	99.8	=
Goosegrass - 14 DAA - LSD _t = 15.69									
120	42.4	50.0	=	66.4	70.0	=	71.0	82.3	=
240	55.0	58.1	=	61.0	74.9	=	67.0	85.2	-
480	49.0	50.1	=	49.6	70.1	-	68.0	82.4	=
Goosegrass - 28 DAA - LSD _t = 16.83									
120	58.0	69.0	=	98.8	95.4	=	95.4	100.0	=
240	76.2	69.0	=	88.0	95.4	=	99.2	100.0	=
480	75.0	69.0	=	77.0	95.4	-	97.6	100.0	=

¹Observed values; ²Expected values; ³Interaction analysis, considering LSD test applied at 5% significance level, where (+) refers to the synergistic mixture, (=) refers to the additive mixture and (-) refers to the antagonistic mixture.

Results with antagonistic interaction of graminicides associated with latifolicides are more common in the literature. PEREIRA et al. (2018) comment that using haloxyfop + glyphosate associated to the auxinic herbicides 2,4-D and dicamba promoted reduction in sourgrass control when compared to treatments with haloxyfop + glyphosate, haloxyfop + glyphosate + halauxifen + diclosulam, haloxyfop + glyphosate + halauxifen or haloxyfop + glyphosate + diclosulam. The most effective treatments did not have auxinic herbicides in the mixture

Combinations of dicamba-quizalofop-p-ethyl and dicamba-clethodim were adopted for controlling voluntary corn (UNDERWOOD et al. 2016), where using a dicamba-quizalofop mixture (300 + 24 g ha⁻¹) resulted in an antagonistic effect. However, this effect was not detected when increasing the dose of quizalofop-p-ethyl to 36 g ha⁻¹. Therefore, it is possible that increasing dosage of graminicide contributes to lower antagonistic effect in the mixture. While in relation to RR-corn hybrids control, antagonistic mixture effects were observed in haloxyfop + 2,4-D (25 + 670 g ha⁻¹) at 7 and 14 DAA (MACIEL et al. 2013); however, reasonably satisfactory control levels were found when graminicide was used in isolation, at 7 DAA, at the dose of 25 g ha⁻¹.

In the case of eudicotyledons, factorial interaction was detected for herbicide mixtures applied on horseweed at 28 DAA, for both control and mass of dry matter variables (Table 4). For morning glory, interaction occurred only for control assessments at 14 and 28 DAA (Table 5). In this case, dicamba contribution on controlling broadleaf species was evident, in which the highest dose reached up to 98.4% of horseweed control (Table 4) and 99.8% of morning glory control (Table 5), with effects also on reducing mass of dry matter.

Table 4. Percentage control¹ of horseweed (*Conyza* spp.) evaluated at 14 and 28 DAA² and mass of dry matter evaluated at 28 DAA, after spraying different doses of the herbicides dicamba and haloxyfop, isolated or in mixture. Machado, MG, Brazil, 2018.

Dicamba (g ha ⁻¹)	Haloxyfop (g ha ⁻¹)				Mean
	0	15	30	60	
Control evaluation performed at 14 DAA ²					
0	0.0	0.0	0.0	0.0	0.0 D
120	41.0	44.4	43.4	44.0	43.2 C
240	47.0	58.0	51.4	50.0	51.6 B
480	58.0	60.0	62.6	57.0	59.4 A
Mean	36.5	40.6	39.35	37.75	---
	CV = 17.26	F _{int} = 0.644 ^{ns}	F _{dic} = 318.305*	F _{hlf} = 1.459 ^{ns}	
Control evaluation performed at 28 DAA ²					
0	0.0 D a	0.0 D a	0.0 D a	0.0 B a	0.0
120	52.0 C b	64.0 C a	52.0 C b	62.0 A a	57.5
240	67.0 B b	83.0 B a	74.0 B b	71.0 A b	73.8
480	85.8 A b	98.4 A a	95.4 A a	66.0 A c	86.4
Mean	51.2	61.35	55.35	49.75	---
	CV = 15.21	F _{int} = 4.698*	F _{dic} = 425.205*	F _{hlf} = 7.893*	
Mass of Dry Matter ³ (g plot ⁻¹) evaluated at 28 DAA ²					
0	5.14 D a	4.60 B a	6.38 C b	5.30 B a	5.36
120	1.77 C a	0.98 A a	1.30 B a	1.42 A a	1.37
240	1.13 B a	0.83 A a	0.86 A a	0.94 A a	0.94
480	0.59 A a	0.51 A a	0.49 A a	1.12 A b	0.68
Mean	2.16	1.73	2.26	2.20	----
	CV = 7.40	F _{int} = 3.213*	F _{dic} = 412.838*	F _{hlf} = 4.955*	

¹Means followed by the same letter, uppercase in the columns and lowercase in the rows, do not differ according to Scott-Knott's test, with 5% of significance; ²DAA - days after application; ³Original data presented, previously transformed by $\sqrt{x+1}$; * Significant at the F test, with 1% of significance; ^{ns}F test not significant.

Table 5. Percentage control¹ of morning glory (*Ipomoea triloba*) evaluated at 14 and 28 DAA² and mass of dry matter evaluated at 28 DAA after spraying different doses of the herbicides dicamba and haloxyfop, isolated or in mixture. Machado, MG, Brazil, 2019.

Dicamba (g ha ⁻¹)	Haloxyfop ¹ (g ha ⁻¹)				Mean
	0	15	30	60	
Control evaluation performed at 14 DAA ²					
0	0.0 D a	0.0 D a	0.0 D a	0.0 D a	0.0
120	31.6 C a	31.0 C a	21.8 C b	36.0 C a	30.1
240	43.0 B b	53.0 B a	47.0 B b	61.0 B a	51.0
480	78.0 A a	64.0 A b	64.6 A b	75.0 A a	70.4
Mean	38.2	37.0	33.4	43.0	---
	CV = 20.26	F _{int} = 2.396*	F _{dic} = 308.569*	F _{hlf} = 5.388*	
Control evaluation performed at 28 DAA ²					
0	0.0 D a	0.0 D a	0.0 D a	0.0 D a	0.0
120	30.0 C a	29.0 C a	30.0 C a	35.0 C a	31.0
240	46.4 B c	69.4 B b	64.8 B b	78.0 B a	64.6
480	91.4 A a	91.6 A a	88.8 A a	99.8 A a	92.9
Mean	41.9	47.5	45.9	53.2	---
	CV = 15.42	F _{int} = 3.816*	F _{dic} = 616.228*	F _{hlf} = 8.244*	
Mass of Dry Matter ³ (g plot ⁻¹) evaluated at 28 DAA ²					
0	3.80	3.48	5.76	4.96	4.50 D
120	1.94	1.75	2.03	1.68	1.85 C
240	1.48	1.43	1.69	0.91	1.38 B
480	0.49	0.61	0.77	0.41	0.57 A
Mean	1.93 a	1.82 a	2.56 b	1.98 a	---
	CV = 11.52	F _{int} = 1.577 ^{ns}	F _{dic} = 107.786*	F _{hlf} = 3.415*	

¹Means followed by the same letter, uppercase in the columns and lowercase in the rows, do not differ according to Scott-Knott's test, with 5% of significance; ²DAA - days after application; ³Original data presented, previously transformed by $\sqrt{x+1}$; * Significant at the F test, with 1% of significance; ^{ns}F test not significant.

As expected, different doses of haloxyfop alone did not promote satisfactory control of eudicotyledons. Evaluating mixtures of haloxyfop with the auxinic herbicide 2,4-D for controlling 12-15 leaves horseweed, LEAL (2018) also found that treatments in which herbicide haloxyfop was used alone did not achieve adequate control of the weed, at 35 DAA. This observation is the consequence of differences between ACCase production found in monocots and dicots, in which monocots have only the ACCase-eukaryotic form in the cytoplasm and chloroplast. Only the eukaryotic form of the enzyme is inhibited, so that only grasses are affected by ACCase inhibitors (VIDAL 1997). Weed species that are not grasses are quite tolerant to ACCase-inhibiting herbicides, in which a tolerance mechanism occurs due to insensitivity of the target enzyme (OLIVEIRA Jr. 2011).

For eudicotyledon species, Colby's method (COLBY 1967) of interaction analysis performed for herbicide mixtures is detailed in Table 6. One antagonistic, four synergistic and 13 additive mixtures were found for accumulated evaluations on horseweed. The antagonism detected between dicamba-haloxyfop in the highest doses must be highlighted, i.e., the mixture of 480 + 60 g ha⁻¹ dicamba-haloxyfop. This mixture may have field recurrent adoption, resulting in a significant antagonistic effect. For morning glory, three antagonistic, five synergistic and 10 additive interactions were detected. For this species, the occurrence of synergy was more evident when adopting the intermediate dose of dicamba of 240 g ha⁻¹ (Table 6).

Table 6. Interaction analysis of dicamba-haloxyfop tank mixtures at 14 and 28 days after application (DAA) on horseweed (*Conyza* spp.) and morning glory (*Ipomoea triloba*). Machado, MG, Brazil, 2018/19.

Dicamba (g ha ⁻¹)	Haloxyfop (g ha ⁻¹)								
	15			30			60		
	Obs. ¹	Exp. ²	Int. ³	Obs. ¹	Exp. ²	Int. ³	Obs. ¹	Exp. ²	Int. ³
Horseweed - 14 DAA - LSD _t = 8.41									
120	44.0	41.0	=	43.4	41.0	=	44.0	41.0	=
240	58.0	47.0	+	51.4	47.0	=	50.0	47.0	=
480	60.0	58.0	=	62.6	58.0	=	57.0	58.0	=
Horseweed - 28 DAA - LSD _t = 10.47									
120	64.0	52.0	+	52.0	52.0	=	62.0	52.0	=
240	83.0	67.0	+	74.0	67.0	=	71.0	67.0	=
480	98.4	85.8	+	95.4	85.8	=	66.0	85.8	-
Morning glory - 14 DAA - LSD _t = 9.71									
120	31.0	31.6	=	21.8	31.6	-	36.0	31.6	=
240	53.0	43.0	+	47.0	43.0	=	61.0	43.0	+
480	64.0	78.0	-	64.6	78.0	-	75.0	78.0	=
Morning glory - 28 DAA - LSD _t = 9.20									
120	29.0	30.0	=	30.0	30.0	=	35.0	30.0	=
240	69.4	46.4	+	64.8	46.4	+	78.0	46.4	+
480	91.6	91.4	=	88.8	91.4	=	99.8	91.4	=

¹Observed values; ²Expected values; ³Interaction analysis, considering LSD test applied at 5% significance level, where (+) refers to the synergistic mixture, (=) refers to the additive mixture and (-) refers to the antagonistic mixture.

When studying mixtures of auxinic and ACCase-inhibiting herbicides in an agricultural area with simultaneous presence of horseweed and sourgrass, OSIPE (2015) reported antagonism for some treatments at the control evaluation of 35 DAA, as verified for dicamba + quizalofop, 2,4-D + clethodim and 2,4-D + quizalofop when applied for controlling sourgrass. On the other hand, it is noteworthy that dicamba adoption in agricultural systems is an excellent alternative for the management of hard-to-kill eudicotyledons, especially for horseweed biotypes resistant to other modes of action, like ALS and EPSPS-inhibiting herbicides (SOARES et al. 2012).

Among possible explanations for the antagonism occurrence in herbicide mixtures, there is a reduction in the molecule's absorption (CULPEPPER et al. 1999, BROMMER et al. 2000) or a reduction in graminicides translocation caused by latifolicides (HOLSHOUSER & COBLE 1990, TREZZI et al. 2007). Another possibility is the reduction of metabolic activities, such as cell division and the supply of lipids for membrane synthesis, compromising the activity of ACCase inhibitors (TREZZI et al. 2007).

Although uncommon in the literature, the possibility of synergistic effect of the mixture was also observed, as identified in four interactions on monocots (Table 3) and in nine interactions on eudicots (Table 6). When synergistic effect occurs in an herbicide mixture, the reasons for this occurrence may be connected to a few factors, such as: increased leaf penetration of post-emergence applied herbicides, increased herbicide translocation or even interactions of modes of action (SILVA et al. 2007, AGOSTINETO et al.

2016). In the case of the dicamba-haloxyfop mixture, the most likely hypothesis is the joint collaboration of the adjuvants present in both formulations, with a better result in leaf penetration, which may contribute to higher final efficacy, since each mode of action is specific to a group of plant species.

CONCLUSION

Antagonistic, additive and synergistic effects were observed in dicamba-haloxyfop mixtures, with a greater preponderance of additive effects. Considering all four plant species, in different doses and moments of evaluation, 72 mixtures of dicamba and haloxyfop were analyzed, in which 50 were considered additive. However, the possibility of antagonism (9 interactions) or even synergy (13 interactions) cannot be ruled out, considering the influence of the herbicide dose, plant species and time of evaluation.

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