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Shading after application affects the efficacy of post-emergence herbicides

Saul Jorge Pinto de Carvalho[1], Leticia Caroline de Oliveira[2], Rafaela Souto Pereira[1], Ramiro Fernando Lopez Ovejero[3], Gilmar José Picoli Junior[3], Dyrson de Oliveira Abbade Neto[3]

[1] Instituto Federal de Educação, Ciência e Tecnologia do Sul de Minas Gerais, Câmpus Machado, Machado, Minas Gerais, Brasil. E-mail: sjpcarvalho@yahoo.com.br, rafaela.souto@alunos.ifsuldeminas.edu.br

[2] Universidade Federal de Alfenas, Alfenas, Minas Gerais, Brasil. E-mail: leticiacaroline.oliveira@sou.unifal-mg.edu.br

[3] Bayer Crop Science do Brasil, São Paulo, São Paulo, Brasil. E-mail: ramiro.ovejero@bayer.com, gilmar.picoli@bayer.com, dyrson.neto@bayer.com

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ABSTRACT

Light and shading after application play an important role on herbicide efficacy, however its effect on different mechanisms of action is not well understood. Therefore, this work was developed with the objective of evaluating the effect of shading on the efficacy of post-emergence application of herbicides with different mechanisms of action. Five independent greenhouse experiments were carried out in Machado - MG, using the herbicides atrazine (500 and 1,000 g ha^{-1}), dicamba (240 and 480 g ha^{-1}), diquat (200 and 400 g ha^{-1}), saflufenacil (24.5 and 49.0 g ha^{-1}), and tembotrione (50.4 and 100.8 g ha^{-1}). *Ipomoea triloba* plants were used as bioindicator at the phenological stage of 5-6 leaves. The effect of shading was evaluated after applications, once plants were subjected to a period of 48 hours of altered light incidence in all treatments with this factor. A (2×3)+1 factorial arrangement was used for each experiment, consisted of two herbicide rates, three shading levels (100% shade screen, 50% shade screen, and no shade screen), and checkplots without application of herbicides. The shading environment consisted of small chambers fully covered with the respective shade screens (50% and 100%). During the trials, herbicide efficacy was evaluated weekly, as well as dry matter at the end of the period. The efficacy of the herbicides was not hindered by shading after applications. The shading had no significant effect on the efficacy of the herbicide dicamba. The efficacy of atrazine was slightly higher when the plants were kept in the shading chamber after application. Shading after application contributed positively for the efficacy of the herbicides diquat and tembotrione. The herbicides dicamba, diquat, and saflufenacil were effective for post-emergence control of *I. triloba*.

Keywords: *Ipomoea triloba*, Light, Physiology, Application, Environment.

Sombreamento após aplicação interfere na eficácia de herbicidas pós-emergentes

RESUMO

A luminosidade e o sombreamento após a aplicação de herbicidas possuem um importante papel em sua eficácia de herbicidas, contudo este efeito sobre diferentes mecanismos de ação não é bem compreendido. Assim, este trabalho foi desenvolvido com o objetivo de avaliar o efeito do sombreamento após aplicação em pós-emergência de herbicidas com diferentes mecanismos de ação. Cinco experimentos distintos foram realizados em casa-de-vegetação em Machado - MG, utilizando-se os herbicidas atrazina (500 e 1,000 g ha^{-1}), dicamba (240 e 480 g ha^{-1}), diquat (200 e 400 g ha^{-1}), saflufenacil (24,5 e 49,0 g ha^{-1}), e tembotrione (50,4 e 100,8 g ha^{-1}). A corda-de-viola foi adotada como bioindicador, em estádio fenológico de 5-6 folhas. A influência do sombreamento foi avaliada sempre após as aplicações, administrando-se o período de 48 horas de luminosidade alterada em todos os tratamentos com este fator. Para cada experimento, adotou-se esquema de tratamentos fatorial (2x3)+1, composto por duas doses do herbicida, três níveis de sombreamento (sombrite de 100%, 50% e ausência de sombrite) e testemunha absoluta sem aplicação. O ambiente de sombreamento foi constituído por pequenas câmaras devidamente recobertas com o respectivo sombrite (50 e 100%). Ao longo dos experimentos, a eficácia dos produtos foi avaliada semanalmente, bem como massa de matéria seca ao final dos trabalhos. A eficácia dos herbicidas não foi prejudicada pelo sombreamento após as aplicações. Não houve efeitos significativos do sombreamento sobre a eficácia do herbicida dicamba. A atrazina teve pequeno aumento de eficácia quando as plantas foram mantidas em câmara de sombreamento após aplicação. O sombreamento após a aplicação contribuiu positivamente para a eficácia dos herbicidas diquat e tembotrione. Os herbicidas dicamba, diquat e saflufenacil foram eficazes para controle da corda-de-viola em pós-emergência.

Palavras-chave: *Ipomoea triloba*, Luminosidade, Fisiologia, Pulverização, Ambiente.

1. Introduction

Weeds are an important biotic component in agroecosystems as they can affect agricultural crops by decreasing yield and quality of products, requiring control measures that increase production costs (Carvalho et al., 2021). Currently, the use of herbicides is the most effective method to control weeds, mainly in large crop areas, in which this method is economically viable (Ciuberkis et al., 2010; Schneider et al., 2022; Foloni et al., 2024).

The chemical control method provides several advantages, including reduced reliance on manual labor within the crop environment, effective control in the planting rows with absence of mechanical damage to crops, reduced costs to production systems, viability for crops under minimum tillage and no-tillage systems, and control of weed species that have vegetative propagation (Silva et al., 2007; Agostinetto et al., 2015; Tehulie et al., 2021).

Post-emergence application of herbicides is among the methods used for chemical control of weeds (Alptekin et al., 2023). This application mode refers to the distribution of the herbicide solution on leaves of weed species, through which the molecules will be absorbed and translocated to their acting point, starting processes that will lead to plant death (Krähmer et al., 2021). A wide variety of herbicides and mechanisms of action are available for this application method; the choice should be based on the analysis of the weed community in the area, the crop that is currently being grown or will be planted, and costs involved in the process (Rodrigues and Almeida, 2018; Krähmer et al., 2021; Alptekin et al., 2023).

Although common in agricultural environments, post-emergence application of herbicides is subjected to the effect of several factors connected to plants, herbicides, application technology, and weather conditions at the time and after applications (Durigan, 1992; Almeida et al., 2016; Montgomery et al., 2017). Besides, the period of day as well as the light availability or shading (cloudy days) after application are factors that affect the efficacy of these molecules (Waltz et al., 2004; Stewart et al., 2009; Cieslik et al., 2013). There are some evidences in literature regarding the effects of shading on herbicide efficacy, however only some of them evaluate modern molecules (Montgomery et al., 2017; Spricigo et al., 2021; Kalina et al., 2022).

Many mechanisms of action of herbicides depend on light availability for activation, especially those that inhibit photosynthesis (photosystems I and II), carotenoid synthesis, and Protox (Székáz, 2021; Barker et al., 2023). However, some absence of light after application might contribute to the efficacy of these molecules by favoring herbicide translocation before the onset of lethal effects. This enhanced translocation allows for a better distribution of the chemical product in the plants, resulting in higher efficacy over time (Pitelli et al., 2011; Oliveira et al., 2022)

In this sense, the hypothesis raised is that weather conditions before and after post-emergence applications might affect the efficacy of herbicides, requiring experiments based on different mechanisms of action. Therefore, this study was developed with the objective of evaluating the effect of shading on the efficacy of post-emergence applications of herbicides with different mechanisms of action.

2. Material and Methods

Five greenhouse experiments were carried out at the Federal Institute of South of Minas Gerais, in Machado, MG, Brazil (21°40'S, 45°55'W, and altitude of 850 m), from September 2022 to April 2024, to evaluate the effect of shading on the efficacy of different herbicides. Separate experiments were carried out for each herbicide. The experiments were carried out using 3-liter pots filled with a mixture of commercial substrate and sieved clay soil (2:1 v v^{-1}). The soil in the pots was fertilized and maintained under automatic irrigation to prevent nutrient or water deficiency.

Seeds of *Ipomoea triloba*, used as bioindicator in the experiments, were acquired from commercial suppliers and distributed on plastic trays with capacity of 2 L filled with commercial substrate. After seedling emergence, three healthy specimens at the cotyledon leaf phenological stage were transplanted into each pot. A density of three plants per pot was maintained until the end of the experiments.

The effect of shading was evaluated after applications, once plants were subjected to a period of 48 hours of altered light incidence in all treatments with this factor. A (2×3)+1 factorial arrangement was used for each experiment, consisting of two herbicide rates, three shading levels (100% shade screen, 50% shade screen, and no shade screen), and checkplots without herbicide application. The experiments were implemented in randomized blocks with four replications. Plants were organized by size, even those with small differences, for characterization of the block factor. The herbicides and respective rates adopted were (g a.i. ha^{-1}): atrazine at 500 and 1,000, dicamba at 240 and 480, diquat at 200 and 400, saflufenacil at 24.5 and 49.0, and tembotrione at 50.4 and 100.8.

The shading environment consisted of small chambers fully covered with the respective shade screen (50% and 100%). Shading chambers with length of 0.5 m, width of 0.5 m, and height of 0.6 m were built using half-inch PVC pipes. The shade screen was manually cut and sewed to the PVC structure. Plants were kept on benches inside the small chambers for 48 hours after each herbicide application, and a 100% shade screen was placed under the pots to avoid the entry of diffuse light into the chambers (Figure 1).

Figure 1. *Ipomoea triloba* plants maintained under the effect of different light conditions in shading chambers after application of herbicides. Chamber with 100% shade screen (left); chamber with 50% shade screen (right). Machado, MG, Brazil 2022.

I. triloba plants were at the phenological stage of 5-6 leaves at the time of applications. The plants were removed from the greenhouse and the applications were carried out in an open, wind-free environment using a CO_2-pressurized backpack sprayer coupled to a spray boom with two nozzles (XR 110.02) spaced 0.50 m apart, calibrated to apply 200 L ha^{-1}, and positioned at 0.50 m above the target.

The percentage of weed control (efficacy) was evaluated at 2, 7, 14, 21, and 28 days after application (DAA), depending on the speed of the mechanism of action of the herbicide. The herbicides saflufenacil and diquat have rapid contact action, thus, they were evaluated at 2 DAA, immediately after removing the shading chambers. Herbicide efficacy was assessed using a percentage damage scale from zero to 100%, in which zero represented healthy plants and 100% represent dead plants (SBCPD, 1995).

The remaining plant material in the pots was collected at 28 DAA, labeled, and dried in a forced-air oven at 70 °C for 72 hours to obtain the dry matter. The percentage of dry matter was determined by dividing the weight obtained in each plot by the weight obtained in the checkplot of the same block. The data were analyzed by the F test in the analysis of variance, and the means were grouped by the Scott-Knott’s test at a 5% significance level (Scott e Knott, 1974).

3. Results and Discussion

The mechanisms of action and the speed and pattern of symptom manifestation should be considered for understanding the effect of shading on the efficacy of herbicides. In this sense, the most important data were presented according to each mechanism of action and evaluation time. Therefore, the availability of light after application is connected to the mechanism of action of atrazine, which explains the occurrence of the shading effect at 21 DAA and the interaction effect at 28 DAA (Table 1). Atrazine efficacy was greater in plants subjected to 100% shade screen for 48 hours at 21 DAA compared to plants under 50% shade screen or no shade. Similar results were found at 28 DAA, but only for the highest atrazine rate (1,000 g ha^{-1}) (Table 1).

Atrazine acts as a photosystem II inhibiting herbicide in plants, disrupting electron flow between photosystems II and I during the photosynthesis process (Wu et al., 2021). In this case, chlorophyll receives sunlight and reaches an excited state, charged with the electron generated from water photolysis, but remains unable to return to its neutral state (uncharged), maintaining this excited state with excess energy (triplet chlorophyll), which subsequently causes the formation of free radicals with lipid peroxidation and cell damage (Wu et al., 2021).

These results are probably due to better translocation of the molecule in the plants in the environment without light. The presence of light results in the destruction of leaf tissues, which impairs atrazine translocation and, consequently, its efficacy.

Table 1. Efficacy of atrazine on *Ipomoea triloba* plants subjected to different shading levels after application, evaluated at 14, 21, and 28 days after application (DAA), and dry matter percentage[1] evaluated at 28 DAA. Machado, MG, Brazil 2022.

Atrazine ($g\ ha^{-1}$)	Shading (48 hours after application) No shading	50% shade screen	100% shade screen	Mean
Efficacy at 14 DAA				
500	33.7	37.5	35.0	35.4 A
1,000	45.0	46.3	48.8	46.7 B
Mean	39.4	41.9	41.9	---
$F_{rate} = 21.91^{**}$ $F_{shading} = 0.48^{NS}$ $F_{interaction} = 0.36^{NS}$ CV(%) = 14.34				
Efficacy at 21 DAA				
500	31.3	38.7	38.8	36.3
1,000	35.0	37.5	48.8	40.4
Mean	33.1 b	38.1 b	43.8 a	---
$F_{rate} = 2.34^{NS}$ $F_{shading} = 5.09^{*}$ $F_{interaction} = 1.43^{NS}$ CV(%) = 17.39				
Efficacy at 28 DAA				
500	23.8 A a	30.0 A a	23.5 B a	25.8
1,000	29.0 A b	26.3 A b	38.8 A a	31.3
Mean	26.4	28.1	31.1	---
$F_{rate} = 10.28^{**}$ $F_{shading} = 2.54^{NS}$ $F_{interaction} = 9.93^{**}$ CV(%) = 14.94				
Dry matter (%)[1]				
500	59.9	53.5	49.1	54.2 B
1,000	44.6	48.8	43.6	45.7 A
Mean	52.3	51.2	46.3	---
$F_{rate} = 5.48^{*}$ $F_{shading} = 1.00^{NS}$ $F_{interaction} = 0.87^{NS}$ CV(%) = 17.87				

[1]Dry matter percentage evaluated as percentage of residues relative to the checkplot of each block; ** significant at 1% by the F test; * significant at 5% by the F test; NS = not significant by the F test; Means followed by the same uppercase letter in the columns or lowercase letter in the rows are not significantly different from each other by the Scott-Knott test at a 5% significance level.

In general, applications of atrazine alone were not sufficient to control *Ipomoea triloba* plants, resulting in high dry matter percentage of plant residues (Table 1). Campos et al. (2012) evaluated the herbicide diuron, which has the same mechanism of action as atrazine, and found greater efficacy of diuron when plants were subjected to shading after pre- and post-emergence applications, regardless of the rate used.

The herbicide dicamba belongs to the benzoic acid group, a class of growth regulators, synthetic auxins, also termed auxin mimic herbicides (Carvalho et al., 2023). The first symptom observed in susceptible plants after application of this herbicide is epinasty of leaves and petioles. Other metabolic functions are affected over time, showing several symptoms, including deformations in the leaf veins and blades (cupping), growth paralysis with root thickening, callus formation and abnormal tissue growth, disturbances in meristematic regions, and death of buds; death of susceptible plants occurs slowly, within 3 to 5 weeks after application (Christoffoleti et al., 2015; Carvalho et al., 2023).

Therefore, the mechanism of action of dicamba is not directly related to light intensity, which is consistent with the results found (Table 2). The shading effect was generally found only at 7 DAA, with higher herbicide efficacy in plants subjected to 100% shading for 48 hours compared to the others; however, this result was not found in the other evaluations. The efficacy of dicamba was affected by the application rates in all evaluations; the rate of 480 $g\ ha^{-1}$ was the most effective in controlling *I. triloba* plants, reaching a mean control of 96.2% at 28 DAA (Table 2). The mean of dry matter percentage collected in the pots was lower than 10%, confirming the high efficacy of this molecule.

The shading effect on the efficacy of dicamba was not significant when using the recommended rate. Therefore, in field condition, light intensity in the days following dicamba application may have little effect on its efficacy. According to Spricigo et al. (2021), the combination of dicamba with glyphosate was effective in controlling the bioindicator, regardless of the application time. In this case, the application time had higher effect on efficacy only when herbicides were applied alone and using the lowest rates.

Montgomery et al. (2017) evaluated several herbicides to control horseweed (*Conyza canadensis*) and found that the time of day of application affects herbicide efficacy.

In the case of dicamba, they reported slightly higher efficacy for applications near midday (around 12:00 PM); however, the final efficacy varied between 88%, 94%, and 88% for dawn, midday, and dusk applications, respectively. Similarly, Kalina et al. (2022) found higher efficacy for glyphosate + dicamba when applied between midday and one hour before sunset.

However, experiments evaluating different application times throughout the day are more prone to weather variations, which can undoubtedly affect the final efficacy of the herbicide, sometimes more significantly than the molecule properties.

Table 2. Efficacy of dicamba on *Ipomoea triloba* plants subjected to different shading levels after application, evaluated at 7, 14, and 28 days after application (DAA), and dry matter percentage[1] evaluated at 28 DAA. Machado, MG, Brazil 2022.

Dicamba	Shading (48 hours after application)			
($g\ ha^{-1}$)	No shading	50% shade screen	100% shade screen	Mean
Efficacy at 7 DAA				
240	53.8	60.0	70.0	61.3 B
480	70.0	67.5	73.8	70.4 A
Mean	61.9 b	63.8 b	71.9 a	---
F_{rate} = 9.03** $F_{shading}$ = 4.05* $F_{interaction}$ = 1.47^{NS} CV(%) = 11.35				
Efficacy at 14 DAA				
240	62.5	69.3	73.3	68.3 B
480	91.5	88.8	89.8	90.0 A
Mean	77.0	79.0	81.5	---
F_{rate} = 16.32** $F_{shading}$ = 0.24^{NS} $F_{interaction}$ = 0.49^{NS} CV(%) = 16.59				
Efficacy at 28 DAA				
240	67.5	73.8	82.8	74.7 B
480	96.8	95.8	96.0	96.2 A
Mean	82.1	84.8	89.4	---
F_{rate} = 22.74** $F_{shading}$ = 0.88^{NS} $F_{interaction}$ = 1.05^{NS} CV(%) = 12.93				
Dry matter (%)[2]				
240	29.6	22.2	15.9	22.5 B
480	8.5	9.2	9.5	9.1 A
Mean	19.0	15.7	12.7	---
F_{rate} = 14.17** $F_{shading}$ = 0.80^{NS} $F_{interaction}$ = 1.16^{NS} CV(%) = 26.37				

[1]Dry matter percentage evaluated as percentage of residues relative to the checkplot of each block; [2]Original data transformed by $\sqrt{x+1}$; ** significant at 1% by the F test; * significant at 5% by the F test; NS = not significant by the F test; Means followed by the same uppercase letter in the columns or lowercase letter in the rows are not significantly different from each other by the Scott-Knott test at a 5% significance level.

Diquat is a photosystem I-inhibiting herbicides that disrupt the electron transfer step responsible for reducing NADP into NADPH. Diquat diverts electrons from their regular transfer pathway to oxygen, resulting in superoxide formation. This electron diversion causes the formation of free radicals in the forms of superoxide, hydrogen peroxide, and hydroxyl radicals. This results in lipid peroxidation in cell membranes, causing cell leakage and death of leaf tissues (Lima-Melo et al., 2019; Oliveira et al., 2022).

This denotes a strong correlation between the mechanism of action of diquat and shading conditions, showing the effect of shading on its efficacy even at 2 DAA (Table 3). Therefore, a delay in the molecule efficacy was found at 2 DAA when plants were subjected to 100% shading. The importance of light incidence for foliar damage was evident in this evaluation, as a mean damage of only 33.1% was found for 100% shading (Table 3). However, opposite results were found in subsequent evaluations; more symptoms were found in plants under 100% shading, reaching high control (96.8%) at 28 DAA for the diquat rate of 1,000 $g\ ha^{-1}$ (Table 3).

The action of diquat in plants is fast, thus, causing tissue damage that hinders the overall molecule translocation within the plant (Montgomery et al., 2017; Oliveira et al., 2022). Therefore, the diquat translocation in plants is probably higher when they are kept in darkness for 48 hours. Initially, the absence of light delayed the control of *I. triloba* plants, but subsequently resulted in greater molecule translocation, causing widespread damage to plants, resulting in a high control at 28 DAA, superior to treatments with higher initial light availability (Table 3).

These results are consistent with recommendations for nighttime applications of diquat and paraquat, as often found in scientific works (Pitelli et al., 2011). Similarly, Montgomery et al. (2017) found higher efficacy of paraquat in controlling horseweed with nighttime applications; whereas Oliveira et al. (2022) found that five hours of darkness after diquat application contributed to its efficacy in controlling volunteer maize.

Thus, the action of saflufenacil and diquat in plants is similar, as confirmed by the experimental results (Table 4). In the first evaluation (2 DAA), fewer leaf symptoms were observed in plants under 100% shading compared to those under the other light conditions. However, at 7 DAA, the herbicide had a high efficacy in controlling *I. triloba* plants, reaching 100% control in all treatments.

These results are consistent with those of Carvalho et al. (2020), who found high efficacy of saflufenacil for species of the Convolvulaceae family, even when the herbicide was applied at low rates.

Saflufenacil is an herbicide that inhibits the enzyme protoporphyrinogen IX oxidase (Protox) (Grossmann et al., 2011), which is the final enzyme common in the biosynthetic pathways of the heme group and chlorophyll (Dalazen et al., 2015; Presoto et al., 2020). Blocking Protox in chloroplasts results in the accumulation of protoporphyrin-IX in the cytoplasm.

Table 3. Efficacy of diquat on *Ipomoea triloba* plants subjected to different shading levels after application, evaluated at 2, 14, and 28 days after application (DAA), and dry matter percentage[1] evaluated at 28 DAA. Machado, MG, Brazil 2022.

Diquat	Shading (48 hours after application)			
(g ha^{-1})	No shading	50% shade screen	100% shade screen	Mean
Efficacy at 2 DAA				
200	55.0	66.3	28.8	50.0 B
400	73.3	75.0	37.5	61.9 A
Mean	64.1 a	70.6 a	33.1 b	---
F_{rate} = 17.59**	$F_{shading}$ = 66.34**	$F_{interaction}$ = 1.24^{NS}	CV(%) = 12.44	
Efficacy at 14 DAA				
200	48.8 B c	65.0 B b	91.0 A a	68.3
400	85.8 A a	96.8 A a	98.5 A a	93.7
Mean	67.3	80.9	94.8	---
F_{rate} = 48.47**	$F_{shading}$ = 18.92**	$F_{interaction}$ = 6.19*	CV(%) = 11.05	
Efficacy at 28 DAA				
200	40.0	52.5	80.0	57.5 B
400	69.5	98.0	96.8	87.8 A
Mean	54.8 b	75.3 a	87.9 a	---
F_{rate} = 27.24*	$F_{shading}$ = 11.09*	$F_{interaction}$ = 2.20^{NS}	CV(%) = 19.55	
Dry matter (%)[2]				
200	31.1	11.4	4.4	15.6 B
400	12.2	1.0	1.5	4.9 A
Mean	21.6 b	6.2 a	2.9 a	---
F_{rate} = 14.83*	$F_{shading}$ = 10.78*	$F_{interaction}$ = 1.80^{NS}	CV(%) = 37.61	

[1]Dry matter percentage evaluated as percentage of residues relative to the checkplot of each block; [2]Original data transformed by $\sqrt{x+1}$; ** significant at 1% by the F test; * significant at 5% by the F test; NS = not significant by the F test; Means followed by the same uppercase letter in the columns or lowercase letter in the rows are not significantly different from each other by the Scott-Knott test at a 5% significance level.

Protoporphyrin-IX is a photodynamic pigment, and its accumulation in the cytoplasm, combined with presence of light and molecular oxygen, originates singlet oxygen (O^-). This highly reactive free radical causes lipid peroxidation in cell membranes, resulting in cell death (Dalazen et al., 2015; Barker et al., 2023). The efficacy of the herbicide tembotrione and the dry matter percentage of plants were affected by shading in all evaluations.

The interaction between shading and herbicide rate significantly affected the percentage of dry matter at 14 and 28 DAA (Table 5). Tembotrione efficacy was greater for plants kept under 100% shading for 48 hours after application.

When the interaction was significant, the positive effect of 100% shading on herbicide efficacy was evident, regardless of the rate applied (Table 5).

Table 4. Efficacy of saflufenacil on *Ipomoea triloba* plants subjected to different shading levels after application, evaluated at 2, and 7 days after application (DAA), and dry matter percentage[1] evaluated at 28 DAA. Machado, MG, Brazil 2022.

Saflufenacil	Shading (48 hours after application)			
(g ha^{-1})	No shading	50% shade screen	100% shade screen	Mean
Efficacy at 2 DAA				
24.5	85.0	78.8	43.8	69.2 B
49.0	90.0	81.3	47.5	72.9 A
Mean	87.5 a	80.0 b	45.6 c	--
F_{rate} = 6.15*	$F_{shading}$ = 290.72**	$F_{interaction}$ = 0.23^{NS}	CV(%) = 5.21	
Efficacy at 7 DAA				
24.5	100.0	100.0	100.0	100.0
49.0	100.0	100.0	100.0	100.0
Mean	100.0	100.0	100.0	---
Data without statistical variability				
Dry matter (%)				
24.5	1.98	2.83	3.59	2.79
49.0	2.27	3.47	2.49	2.74
Mean	2.12 a	3.04 b	3.15 b	---
F_{rate} = 0.04^{NS}	$F_{shading}$ = 5.19*	$F_{interaction}$ = 3.49^{NS}	CV(%) = 25.23	

[1]Dry matter percentage evaluated as percentage of residues relative to the checkplot of each block; ** significant at 1% by the F test; * significant at 5% by the F test; ^{NS} = not significant by the F test; Means followed by the same uppercase letter in the columns or lowercase letter in the rows are not significantly different from each other by the Scott-Knott test at a 5% significance level.

Tembotrione belongs to the class of triketones, inhibitors of the enzyme 4-hydroxyphenylpyruvate dioxygenase (HPPD), which acts in the synthesis of carotenoids. Carotenoids are substances that protect chlorophyll from photodegradation in the presence of light (Mançanares et al., 2018).

Table 5. Efficacy of tembotrione on *Ipomoea triloba* plants subjected to different shading levels after application, evaluated at 7, 14, and 28 days after application (DAA), and dry matter percentage[1] evaluated at 28 DAA. Machado, MG, Brazil 2022.

Tembotrione ($g\ ha^{-1}$)	Shading (48 hours after application)			
	No shading	50% shade screen	100% shade screen	Mean
Efficacy at 7 DAA				
50.4	32.5	33.8	47.5	37.9 B
100.8	46.3	47.5	52.5	48.8 A
Mean	39.4 b	40.6 b	50.0 a	---
F_{rate} = 27.86**	$F_{shading}$ = 10.67**	$F_{interaction}$ = 2.02^{NS}	CV(%) = 11.60	
Efficacy at 14 DAA				
50.4	33.8 B b	37.5 B b	64.5 A a	45.3
100.8	48.3 A c	56.3 A b	67.5 A a	57.3
Mean	41.0	46.9	66.0	---
F_{rate} = 34.57**	$F_{shading}$ = 53.94**	$F_{interaction}$ = 5.24*	CV(%) = 9.81	
Efficacy at 28 DAA				
50.4	21.3	23.8	48.8	31.3 B
100.8	33.8	42.5	71.3	49.2 A
Mean	27.5 c	33.1 b	60.0 a	---
F_{rate} = 116.05**	$F_{shading}$ = 145.42**	$F_{interaction}$ = 3.08^{NS}	CV(%) = 10.13	
Dry matter (%)				
50.4	46.3 B b	46.1 B b	12.4 A a	34.9
100.8	23.6 A b	15.3 A b	5.6 A a	14.8
Mean	34.9	30.7	9.0	---
Frate = 52.78**	Fshading = 33.66**	Finteraction = 6.47**	CV(%) = 27.29	

[1]Dry matter percentage evaluated as percentage of residues relative to the checkplot of each block; ** significant at 1% by the F test; * significant at 5% by the F test; NS = not significant by the F test; Means followed by the same uppercase letter in the columns or lowercase letter in the rows are not significantly different from each other by the Scott-Knott test at a 5% significance level.

By inhibiting HPPD, tembotrione disrupts carotenoid production. This impairs chlorophyll function in photosynthesis, compromising its ability to capture light energy, resulting in a characteristic bleaching of weed leaves that progress to desiccation and death of plants. These visible symptoms typically appear within a few days of herbicide application (Karam et al., 2009).

Although the mechanism of action of tembotrione is connected to the incidence of light on plants after application, keeping the plants in darkness for 48 hours probably improved molecule translocation before the occurrence of leaf tissue damage. Moreover, this dark period may have contributed to the consumption of reserve sugars and photoassimilates that would be important in detoxification processes; however, the depletion of these reserves contributed to higher herbicide efficacy (Table 5).

4. Conclusions

The efficacy of the herbicides was not hindered by shading after applications; shading had no significant effect on the efficacy of the herbicide dicamba; atrazine efficacy was slightly increased when plants were kept in the shading chamber after application; shading after application contributed to the efficacy of diquat and tembotrione; the herbicides dicamba, diquat, and saflufenacil were effective in post-emergence control of *Ipomoea triloba* plants.

Authors' Contribution

Conceptualization and methodology: Saul Jorge Pinto de Carvalho, Ramiro Fernando López Ovejero. Data collection and curation: Letícia Caroline de Oliveira, Rafaela Souto Pereira. Statistical analysis: Saul Jorge Pinto de Carvalho. Data interpretation and writing: Saul Jorge Pinto de Carvalho, Letícia Caroline de Oliveira, Rafaela Souto Pereira. Original draft preparation and reviewing: Saul Jorge Pinto de Carvalho, Dyrson de Oliveira Abbade Neto, Gilmar José Picoli Junior. Review and editing: Gilmar José Picoli Junior, Dyrson de Oliveira Abbade Neto, Ramiro Fernando López Ovejero. All authors read and approved the final version of the manuscript.

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