https://doi.org/10.71252/2177-34912025720002
ISSN: 2177-3491
revista Ceres

Terbuthylazine, atrazine, and atrazine + mesotrione for weed control in second-crop maize in Brazil[1]

Leandro Paiola Albrecht[2], *Alfredo Junior Paiola Albrecht*[2], *Aderlan Ademir Bottcher*[3,4], *Matheus Greguer de Carvalho*[3,4], *Maikon Tiago Yamada Danilussi*[5], *André Felipe Moreira Silva*[4*], *Willian Felipe Larini*[5], *Rafael Tanaka Torigoe*[6]

[1] This work derives from experiments related to master's thesis of Aderlan Ademir Bottcher.

[2] Universidade Federal do Paraná, Departamento de Ciências Agronômicas, Palotina, PR, Brazil. lpalbrecht@yahoo.com.br; ajpalbrecht@yahoo.com.br

[3] Universidade Estadual de Maringá, Programa de Pós-Graduação em Ciências Agrárias, Umuarama, PR, Brazil. aderlanbottcher@yahoo.com; matheusagroufpr@gmail.com

[4] Crop Science Pesquisa e Consultoria Agronômica (Crop Pesquisa), Maripá, PR, Brazil. afmoreirasilva@alumni.usp.br

[5] Universidade Federal do Paraná, Programa de Pós-Graduação em Agronomia – Produção Vegetal, Curitiba, PR, Brazil. maikondanilussi@gmail.com; willian.larini@gmail.com

[6] Iharabras S.A. Indústrias Químicas (Ihara), Sorocaba, SP, Brazil. rafael.tanaka@ihara.com.br

*Corresponding author: afmoreirasilva@alumni.usp.br

Editors:
Ricardo Alcantara de la Cruz
Teogenes Senna Oliveira

Submitted: April 18th, 2024.
Accepted: December 9th, 2024.

ABSTRACT

Terbuthylazine, as well as atrazine, is a triazine with the mechanism of action of photosystem II (PSII) inhibitors, effective in controlling weeds in maize crops. The aim of this study was to assess the efficacy of terbuthylazine, atrazine, and atrazine + mesotrione, alone or in mixtures with glyphosate, in weed control for post-emergence application in maize. The experiment was conducted over two growing seasons, evaluating weed control, damage symptoms in maize and maize yield. No damage symptoms were observed in maize, and when differences in yield were observed, they were due to differences in treatment efficacy in weed control. The efficacy of terbuthylazine is akin to that of atrazine in controlling broadleaf weeds (until 93.8%) and tends to be superior in controlling grasses (until 87.5% for terbuthylazine, until 76.3% for atrazine) or *Commelina benghalensis* (until 91.3% for terbuthylazine, until 82.5% for atrazine). Terbuthylazine or atrazine + mesotrione, alone or in a mixture with glyphosate, were effective in post-emergence weed control in maize, with a broad spectrum of action. Atrazine, alone or in a mixture with glyphosate, was effective in controlling broadleaf weeds (*Richardia brasiliensis, Bidens subalternans*, and volunteer soybeans).

Keywords: triazines; grasses; broadleaves; Benghal dayflower; *Zea mays*.

INTRODUCTION

To minimize the problems caused by tolerant or resistant weeds, integrated weed management is essential, which includes rotating crops herbicide action mechanisms.[1,2] For maize cultivation, terbuthylazine or atrazine application stands out as an alternative or complementary to glyphosate applications. These herbicides are triazines with the mechanism of action of photosystem II (PSII) inhibitors, effective in controlling weeds in maize crops in pre-emergence or initial post-emergence.[3-6]

As options with a broader spectrum of action in post-emergence of maize, carotenoid biosynthesis inhibitors such as mesotrione combined with PSII inhibitors can be highlighted.[7,8] The pre-formulated atrazine + mesotrione mixture has shown promise,[9] demonstrating synergistic effects in a number of situations.[10,11]

Terbuthylazine has proved to be more effective than atrazine, in mixtures with glyphosate, in controlling *Digitaria* spp.[12] and other grasses,[6] or equivalent to atrazine in controlling broadleaf weeds and Benghal dayflower (*Commelina benghalensis*),[6] in post-emergence application in maize. The literature remains scarce in terms of comparing terbuthylazine and atrazine, especially under growing conditions in Brazil, since terbuthylazine was registered in the country in 2020.

Triazines have low to moderate soil sorption coefficients, moderate water solubility, and low volatility, making them vulnerable to leaching. This can lead to decreased weed control effectiveness and contaminated groundwater.[13] Due to this and other aspects, some herbicides in this group are no longer authorized in some countries; for example, atrazine is not authorized in the European Union, while terbuthylazine is permitted.[14]

It is important to investigate and assess the efficacy of terbuthylazine in weed control in Brazil, especially because of a possible atrazine ban in the country. Thus, the aim of the present study was to assess the efficacy of terbuthylazine, atrazine, and atrazine + mesotrione, alone or in mixtures with glyphosate, in weed control for post-emergence application in maize.

MATERIALS AND METHODS

Site description

The experiment was conducted in the western region of Paraná state (PR), Brazil, in second-crop maize following soybean cultivation between the months of February and July. For the 2020-2021 crop season, the experiment was conducted in two areas in Maripá (area 1: 24°24’31.8”S 53°51’40”W; area 2: 24°24’30”S 53°51’44”W), and for the 2021-2022 crop season, in three areas in Maripá (area 1: 24°25’17.0”S 53°51’57.9”W; area 2: 24°24’33.2”S 53°51’42.7”W) and Francisco Alves (area 3: 24°03’58.2”S 53°48’36.7”W). The region’s climate is classified as Cfa, according to Köppen’s classification, and the meteorological conditions for the period are shown in Figure 1.

The soil of the experimental sites is classified as very clayey for Maripá and sandy for Francisco Alves. No-till planting was performed in the booth crop seasons, planting maize hybrid P3858 PWU in the Maripá areas in both seasons and Feroz VIP3 in Francisco Alves, all of which are tolerant to glyphosate and glufosinate.

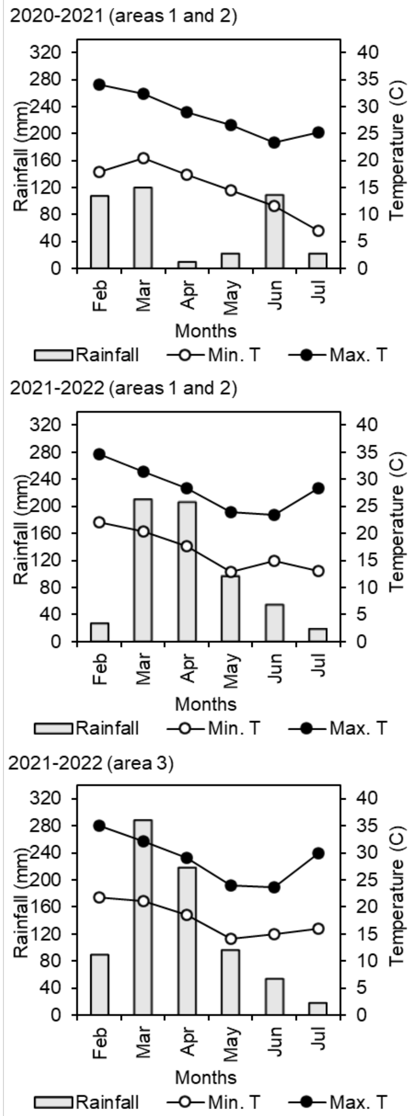
For the 2020-2021 crop season, area 1 was infested with *C. benghalensis* and grasses (*Digitaria* spp., *Urochloa* spp. e *Sorghum* spp.), area 2 with *C. benghalensis*, Brazil pusley (*Richardia brasiliensis*), greater beggarticks (*Bidens subalternans*), sourgrass (*Digitaria insularis*) and *Sorghum* spp. For both areas, there was low infestation at the time of application, new emergency flows were observed from the application to the control evaluation.

For the 2021-2022 crop season, the three areas were infested with *C. benghalensis* (>20 plants m^{-2}) and volunteer soybean (up to 5 plants m^{-2}) in the control (without application) at 35 days after application (DAA). The weeds were already present at the time of application, for *C. benghalensis* increases in infestation were observed due to new emergence flows.

Experimental design

The experiments were arranged in a completely randomized block design with four replications, and the experimental units consisted of 6 x 4 m plots with rows 0.45 m apart. The use of fertilization practices, crop installation and phytosanitary management were carried out in accordance with Embrapa[15] (2015) recommendations.

For the 2020-2021 season, five treatments were used, consisting of the application of terbuthylazine (Sonda®), atrazine (Primóleo®), atrazine + mesotrione (Calaris®). For the 2021-2022 season, six treatments were used, consisting of terbuthylazine, atrazine, atrazine + mesotrione, and glyphosate (Xeque Mate®) (Table 1). Applications occurred in post-emergence of maize (V_4-V_5) using a CO_2 pressurized backpack sprayer equipped with six AIXR 110.015 nozzles (Teejet®), at a pressure of 2 kgf cm^{-2} and a speed of 3.6 km h^{-1}, providing an application volume of 150 L ha^{-1}.



Source: Weather station located in 24°24'29.1"S 53°51'44.6"W (areas 1 and 2). Weather station located in 24°10'44.5"S 53°50'16.8"W (area 3).

Figure 1: Rainfall and temperature for the study period.

Assessments, data collection, and statistical analysis

Weed control was assessed at 35 days after application (DAA), and maize plant damage symptoms at 7, 14, 21, 28, and 35 DAA. For all these assessments, scores were assigned using visual analyses for each experimental unit (0 for no damage, up to 100% for plant death), considering significantly visible symptoms on the plants according to their development.[16] For yield, ears were collected from the 4 central rows along 4 meters of each plot. The grains produced in each plot were weighed, and the moisture content corrected to 13%. Based on these data, yield was calculated in kg ha[1]. For the 2021-2022 crop season, yield was assessed only in area 1.

The data obtained were submitted to analysis of variance (ANOVA) using the F-test ($p < 0.05$), and treatment means were compared using Tukey's test ($p < 0.05$). The analyses were carried out using Sisvar 5.6 software.[17]

RESULTS

2020-21 crop season

The efficacy of treatments for controlling *C. benghalensis* was low in area 1, with a maximum of 18.8%, which may be due to higher initial infestation and the seed bank. In area 2, control reached up to 89.3% with the application of atrazine + mesotrione, not differing from terbuthylazine (1,200 g ai ha^{-1}) with 85.8%, both superior to atrazine, at 70.5% efficacy (Table 2).

The herbicide treatments were equally effective in controlling sourgrass (*Digitaria insularis*), with scores ranging from 76.3 to 92% in area 2. In the overall control of grasses, atrazine was less effective in area 1 with 70%, while other herbicide treatments showed similar efficacy ranging from 82 to 90.8%. Equivalent herbicide treatments were observed in controlling broadleaf weeds, with efficacy ranging from 73.8 to 86.3% for Brazil pusley (*Richardia brasiliensis*) and from 92.5 to 96% for greater beggarticks (*Bidens subalternans*) (Table 2).

The efficacy of weed control treatments affected maize yield, with lower yields observed for treatments with less effective control. For the control without application, yield was 1,640 kg ha^{-1} (area 1) and 2,723 kg ha^{-1} (area 2), the treatments with herbicide applications provided yield of up to 4,336 kg ha^{-1} (area 1) and 3,663 kg ha^{-1} (area 2) (Figure 2). Weed interference with yield was confirmed by the absence of damage symptoms on maize plants due to herbicide application.

2021-2022 crop season

In area 1, herbicide treatments did not differ, with control scores ranging from 82.5 to 90.3% for *C. benghalensis*. In area 2, the highest control was 55%, achieved with atrazine + mesotrione + glyphosate, similar to terbuthylazine (1,200 g ai ha^{-1}) + glyphosate, with 50%. In area 3, the most effective treatments were terbuthylazine + glyphosate at doses of 1,200 and 1,000 g ai ha^{-1}, achieving control rates of 85 and 91.3%, respectively. Terbuthylazine (1,200 g ai ha^{-1}) + glyphosate was the only treatment consistently effective in controlling *C. benghalensis* in the three areas (Table 3).

Table 1: Treatments composed of the application of herbicides applied in post-emergence (V_4-V_5) of maize plants, for weed control

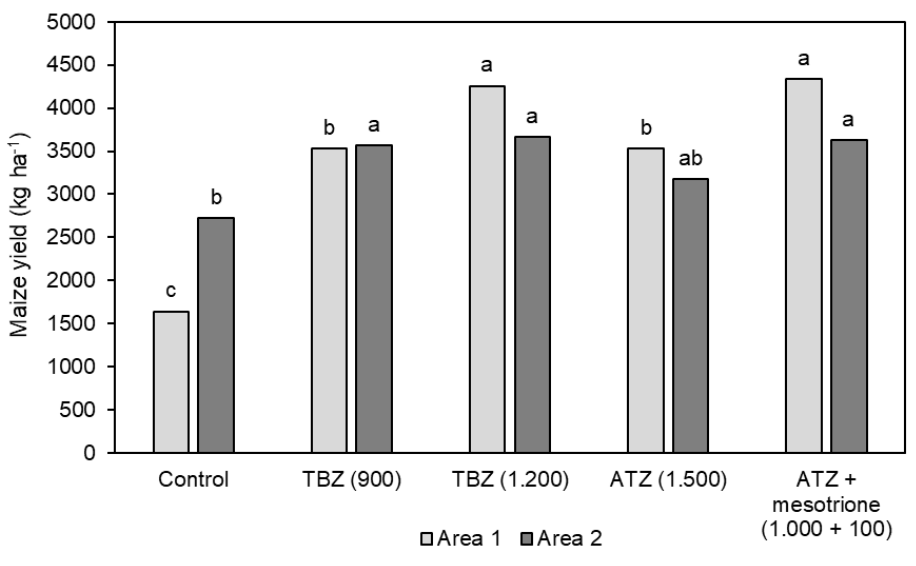
2020-2021 crop season		2021-2022 crop season	
Herbicide	**Dose**	**Herbicide**	**Dose**
	g ai ha^{-1}		g ai ha^{-1}
Control (without application)	-	Control (without application)	-
TBZ[1]	900	TBZ + glyphosate[3]	900 + 1.250
TBZ[1]	1.200	TBZ + glyphosate	1.000 + 1.250
ATZ	1.500	TBZ + glyphosate	1.200 + 1.250
ATZ + mesotrione[2]	1.000 + 100	ATZ + glyphosate	1.200 + 1.250
		[ATZ + mesotrione] + glyphosate	[1.000 + 100] + 1.250

TBZ: terbuthylazine. ATZ: atrazine. [1]Addition of adjuvant mineral oil (Iharol Gold®, 0.25% v:v). [2]Addition of adjuvant mineral oil (Ochima®, 0,25% v:v). [3]Dose at g ae ha^{-1} for glyphosate.

Table 2: Weed control at 35 days after post-emergence herbicide application in maize, 2020-2021 crop season

	Area 1		Area 2				
Herbicide (dose - g ai ha^{-1})	***Commelina benghalensis***	**Grasses**	***Commelina benghalensis***	***Richardia brasiliensis***	***Digitaria insularis***	***Bidens subalternans***	***Sorghum* spp.**
				%			
Control	0.0 b	0.0 d	0.0 c	0.0 b	0.0 b	0.0 b	0.0 d
TBZ (900)	0.0 b	79.5 b	82.0 a	85.0 a	87.5 a	92.5 a	50.0 c
TBZ (1.200)	16.3 a	85.8 ab	86.3 a	86.3 a	87.5 a	93.8 a	67.5 b
ATZ (1.500)	2.0 b	70.5 c	70.0 b	73.8 a	76.3 a	93.8 a	47.5 c
ATZ + mesotrione (1,000 + 100)	18.8 a	89.3 a	90.8 a	85.3 a	92.0 a	96.0 a	81.3 a
Mean	7.4	65.0	65.8	66.1	68.7	75.2	49.3
CV (%)	45.5	4.9	7.5	11.3	10.3	4.5	10.7
F	30.5*	543.1*	230.1*	100.5*	120.7*	620.2*	135.6*
P	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TBZ: terbuthylazine. ATZ: atrazine. * Significant by F-test ($p<0.05$), means followed by the same letter in the rows do not differ according to Tukey's test at 5%.



TBZ: terbuthylazine. ATZ: atrazine. Herbicide doses in parentheses in at g ai ha^{-1}.
* Significant by F-test ($p<0.05$), bars of the same color and with the same letter do not differ according to Tukey's test at 5%.

Figure 2: Maize yield under post-emergence application of herbicides, 2020-2021 crop season.

For controlling volunteer soybeans and *B. subalternans*, herbicide treatments showed similar efficacy in all areas, ranging from 72 to 99%. In area 2, terbuthylazine + glyphosate at doses of 1,200 and 1,000 g ai ha^{-1} demonstrated effective control of grasses, achieving rates of up to 87.5%, superior to atrazine + mesotrione + glyphosate (70%) and showing no significant difference from other herbicide treatments (Table 3).

Similar to the previous growing season, no visual damage symptoms were observed in maize plants due to herbicide application. There were no yield differences in area 1, even when compared to the untreated control (2.484 kg ha^{-1}), with average yield for treatments 2.653 kg ha^{-1} (Figure 3).

DISCUSSION

The results of this study demonstrate that terbuthylazine or atrazine + mesotrione, mainly in combination with glyphosate, are effective in controlling *C. benghalensis* in nearly all areas. When atrazine was not combined with mesotrione, it tended to be less effective, which was a noteworthy finding. This differs from the findings of Bottcher et al.[(6)] (2022) who found no differences between atrazine or terbuthylazine in controlling this weed.

Commelina benghalensis is an important weed in affecting maize yield,[(18-20)] and an essential aspect of management systems. The complexity of *C. benghalensis* can be attributed to its high reproductive flexibility, found in various regions worldwide as an exotic species, producing both aerial and underground seeds in addition to reproducing asexually from stem fragments. Furthermore, its recognized glyphosate tolerance hinders chemical control in post-emergence maize.[(21)] *Commelina benghalensis* is a monocotyledon weed but not grass, and is thus not susceptible to grass herbicides, nor are all broadleaf herbicides effective against it.

The use of triazines, beyond the relevance for the control of *C. benghalensis*, is also crucial for controlling volunteer soybeans in maize.[(22,23)] In Brazil, it is common to plant maize as a second crop after soybean in the spring-summer, as in the present study. Other studies underscore the potential of volunteer soybeans to reduce maize yield.[(24,25)] Overall, in the present study, terbuthylazine, atrazine, or atrazine + mesotrione were equally effective in controlling volunteer soybeans.

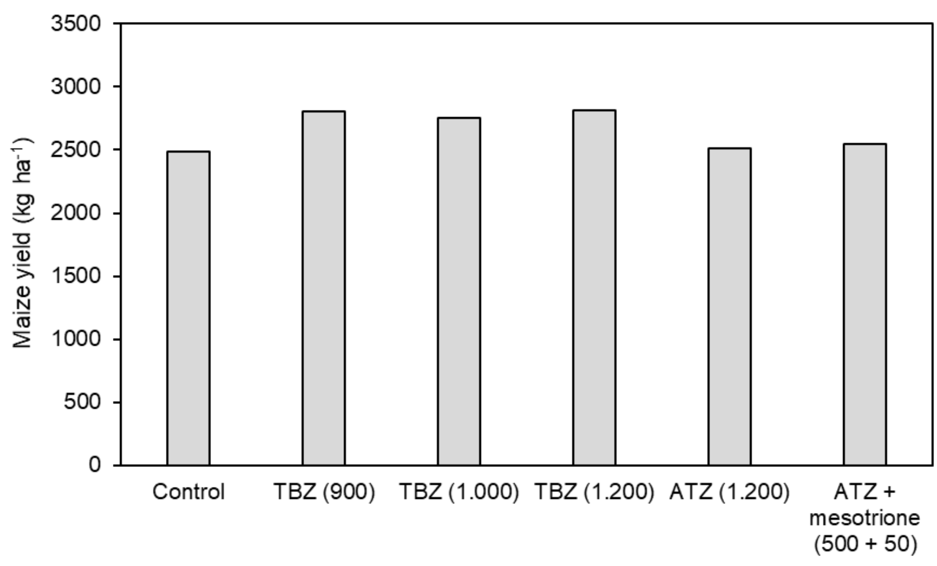
For the control of broadleaf weeds and volunteer soybeans, there was some equivalence among herbicide treatments. The efficacy of terbuthylazine or atrazine is supported by other studies in pre-emergence control of broadleaf weeds in maize, mainly in mixtures with other herbicides.[(26-29)]

Other studies also highlight the efficacy of atrazine + mesotrione in controlling different weed species,[(9,30)] including the effectiveness of the formulated premix,[(6,7)] with noticeable synergism. Mesotrione is an important post-emergent herbicide for weed control in maize.[(8,31-33)] Adding mesotrione is important because it tends to enhance the efficacy of the mixture with atrazine, given that in this study and others, atrazine was less effective against grasses than terbuthylazine.[(6,12)]

Table 3: Weed control at 35 days after post-emergence herbicide application in maize, 2021-2022 crop season

	Area 1		Area 2			Area 3	
Herbicide[1] (dose - g ai ha^{-1})	***Commelina benghalensis***	**Volunteer soybean**	***Commelina benghalensis***	***Bidens subalternans***	**Grasses**	***Commelina benghalensis***	**Volunteer soybean**
				%			
Control	0.0 b	0.0 b	0.0 d	0.0 b	0.0 c	0.0 d	0.0 b
TBZ (900)	85.0 a	98.0 a	10.0 c	83.8 a	77.5 ab	78.8 bc	72.0 a
TBZ (1.000)	87.5 a	99.0 a	28.8 b	90.0 a	86.3 a	85.0 ab	79.3 a
TBZ (1.200)	90.3 a	99.0 a	50.0 a	91.3 a	87.5 a	91.3 a	87.0 a
ATZ (1.200)	82.5 a	99.0 a	30.0 b	81.8 a	73.8 ab	80.0 bc	86.5 a
ATZ + mesotrione (500 + 50)	85.5 a	98.8 a	55.0 a	88.8 a	70.0 b	75.5 c	84.3 a
Mean	71.8	82.3	29.0	72.6	65.8	68.4	68.2
CV (%)	5.4	0.8	13.3	9.4	10.7	4.8	9.8
F	329.3*	1,6367.8*	124.3*	109.6*	87.5*	428.2*	102.5*
P	0.00	0.00	0.00	0.00	0.00	0.00	0.00

[1]Addition of glyphosate (1,250 g ae ha^{-1}) in all herbicide treatments, except the control. TBZ: terbuthylazine. ATZ: atrazine. * Significant by F-test ($p<0.05$), means followed by the same letter in the rows do not differ according to Tukey's test at 5%.



[1]Addition of glyphosate (1,250 g ae ha^{-1}) in all the herbicide treatments, except the control. TBZ: terbuthylazine. ATZ: atrazine. Herbicide doses in parentheses in at g ai ha^{-1}.
[ns] Nonsignificant by F-test (p>0.05), means do not differ by each other.

Figure 3: Maize yield under post-emergence herbicide application, 2021-2022 crop season.

The results of this study indicate the use of terbuthylazine for weed control in maize. The efficacy of terbuthylazine was equivalent to that of atrazine in controlling broadleaf weeds and tends to be better in controlling grasses (*Digitaria insularis*, *Sorghum* spp., and others) or *C. benghalensis*, characterizing terbuthylazine as an alternative solution in weed management in second crop maize in Brazil.

No damage symptoms were observed in maize, and when differences in yield were observed, they were due to differences in treatment efficacy in weed control. In the 2020-2021 crop season, yield in the untreated control was 62.2% (area 1) or 25.7% (area 2) lower compared to the treatment with higher yield. Despite competition with weeds, in the 2021-2022 crop season the untreated control did not show a reduction in yield. This may be related to the low yield observed in the experiment average.

The maize yield in competition with *C. benghalensis* and other weeds was also reduced in a study by Bottcher et al[(6)] (2022), with an average decrease of 36% when chemical control was not performed. Grasses, also found in the present study, can also interfere with agronomic performance in maize, with reductions of approximately 40% in yield.[(34)]

Another noteworthy point in this study is the post-emergence application of glyphosate in maize. The mixture of glyphosate with atrazine is well-established in weed management in this crop.[(35-36)] Triazines display little or no action in post-emergence weed control, with a greater effect in pre-emergence or early post-emergence. In this respect, post-emergence control can be complemented with glyphosate, for example.

In this study, glyphosate was not used in the 2020-2021 crop season due to low weed infestation at the time of application, indicating the possibility of not using this herbicide in post-emergence maize in these situations. Even under conditions of higher infestations in post-emergence, effective control without glyphosate is possible, using mesotrione[(8)] or even glufosinate,[(37)] making it relevant to investigate the efficacy of mesotrione and glufosinate in mixtures with terbuthylazine. It is important to note that glyphosate is an important herbicide for weed control in soybeans and maize, but there are several cases of resistance to this herbicide for many weeds. As such, characterizing management without the use of glyphosate is essential in weed control and preventing resistant biotype selection, in the context of integrated weed management.

CONCLUSION

Terbuthylazine or atrazine + mesotrione, either alone or in combination with glyphosate, was effective in post-emergence weed control in maize, with a broad spectrum of action. Applying atrazine, alone or in combination with glyphosate, was effective in controlling broadleaf weeds.

ACKNOWLEDGEMENTS, FINANCIAL SUPPORT AND FULL DISCLOSURE

The authors would like to thank the *Universidade Estadual de Maringá* (UEM), *Universidade Federal do Paraná* (UFPR), *Supra Pesquisa* team at UFPR, *Crop Pesquisa*, and *Iharabras S.A. Indústrias Químicas* (Ihara).

This study was carried out with the support of the *Coordenação de Aperfeiçoamento de Pessoal de Nível Superior* - Brazil (CAPES) - Financial Code 001.

There is no conflict of interest in conducting and publishing the work.

AUTHOR CONTRIBUTIONS

Conceptualization: Leandro Paiola Albrecht; Alfredo Junior Paiola Albrecht; Aderlan Ademir Bottcher; Matheus Greguer de Carvalho; Rafael Tanaka Torigoe.

Data curation: Leandro Paiola Albrecht; Alfredo Junior Paiola Albrecht; Aderlan Ademir Bottcher; Matheus Greguer de Carvalho; Maikon Tiago Yamada Danilussi; André Felipe Moreira Silva.

Formal analysis: André Felipe Moreira Silva.

Investigation: Leandro Paiola Albrecht; Alfredo Junior Paiola Albrecht; Aderlan Ademir Bottcher; Matheus Greguer de Carvalho; Maikon Tiago Yamada Danilussi; Willian Felipe Larini.

Methodology: Leandro Paiola Albrecht; Aderlan Ademir Bottcher; Maikon Tiago Yamada Danilussi; André Felipe Moreira Silva; Willian Felipe Larini.

Project administration: Leandro Paiola Albrecht; Alfredo Junior Paiola Albrecht; Aderlan Ademir Bottcher; Rafael Tanaka Torigoe.

Software: Aderlan Ademir Bottcher; Matheus Greguer de Carvalho; André Felipe Moreira Silva.

Resources: Leandro Paiola Albrecht; Alfredo Junior Paiola Albrecht; Rafael Tanaka Torigoe.

Supervision: Leandro Paiola Albrecht; Alfredo Junior Paiola Albrecht.

Validation: Leandro Paiola Albrecht; Alfredo Junior Paiola Albrecht.

Visualization: Leandro Paiola Albrecht; Alfredo Junior Paiola Albrecht; André Felipe Moreira Silva; Rafael Tanaka Torigoe.

Writing – original draft: Leandro Paiola Albrecht; Alfredo Junior Paiola Albrecht; Aderlan Ademir Bottcher; André Felipe Moreira Silva.

Writing – review & editing: Matheus Greguer de Carvalho; Maikon Tiago Yamada Danilussi; Willian Felipe Larini; Rafael Tanaka Torigoe.

REFERENCES

1. Adeux G, Munier-Jolain N, Meunier D, Farcy P, Carlesi S, Barberi P, et al. Diversified grain-based cropping systems provide long-term weed control while limiting herbicide use and yield losses. Agron Sustain Dev. 2019;39(42):1-13.
2. Busi R, Powles SB, Beckie HJ, Renton M. Rotations and mixtures of soil-applied herbicides delay resistance. Pest Manag Sci. 2020;76(2):487-96.
3. Andr J, Hejnák V, Jursík M, Fendrychová V. Effects of application terms of three soil active herbicides on herbicide efficacy and reproductive ability for weeds in maize. Plant Soil Environ. 2014;60(10):452-8.
4. Galon L, David FA, Forte CT, Júnior FW, Radunz AL, Kujawinski R, et al. Chemical management of weeds in corn hybrids. Weed Biol Manag. 2018;18 (1):26-40.
5. Langdon NM, Soltani N, Raedar AJ, Hooker DC, Robinson DE, Sikkema H. Time-of-day effect on weed control efficacy with tolpyralate plus atrazine. Weed Technol. 2021;35(1):149-54.
6. Bottcher AA, Albrecht AJ, Albrecht LP, Silva AF, Freitas J, Souza T. Terbuthylazine herbicide: an alternative to atrazine for weed control in glyphosate-tolerant maize. J Environ Sci Health B. 2022;57(8):609-16.
7. Chhokar RS, Sharma RK, Gill SC, Singh RK. Mesotrione and atrazine combination to control diverse weed flora in maize. Indian J Weed Sci. 2019;51(2):145-50.
8. Giraldeli AL, Silva GS, Silva AF, Ghirardello GA, Marco LR, Victoria Filho R. Efficacy and selectivity of alternative herbicides to glyphosate on maize. Rev Ceres. 2019;66(4):279-86.
9. Matte WD, Oliveira RS Junior, Machado FG, Constantin J, Biffe DF, Gutierrez FS, et al. Efficacy of [atrazine + mesotrione] in control of weed in corn. Rev Bras Herb. 2018;17:e587.
10. Woodyard AJ, Bollero GA, Riechers DE. Broadleaf weed management in corn utilizing synergistic postemergence herbicide combinations. Weed Technol. 2009;23(4):513-8.
11. Walsh MJ, Stratford K, Stone K, Powles SB. Synergistic effects of atrazine and mesotrione on susceptible and resistant wild radish (*Raphanus raphanistrum*) populations and the potential for overcoming resistance to triazine herbicides. Weed Technol. 2012;26(2):341-7.
12. Currie RS, Geier PW. Comparisons of terbuthylazine and atrazine rates and tank mixtures in irrigated corn. Kans Agric Exp Stn Res Rep. 2019;5(7):19.
13. Portocarrero R, Aparicio V, Gerónimo E, Costa JL. Soil properties of sugarcane fields controlling triazine leaching potential. Soil Res. 2019;57(7):729-37.
14. EU Pesticides database: Active substances, safeners and synergists [Internet]. Europe: European Commission; 2024 [cited 2024 Mar 24]. Available from: https://ec.europa.eu/food/plant/pesticides/eu-pesticides-database/start/screen/active-substances.
15. Empresa Brasileira de Pesquisa Agropecuária. Sistema de produção. Cultivo do milho, 9th edition [Internet]. Brasília: Embrapa; 2015 [cited 2020 Jan 24]. Available from: https://ainfo.cnptia.embrapa.br/digital/bitstream/doc/486917/1/Sistema-de-Producao-Cultivo-do-Milho.pdf
16. Velini ED, Osipe R, Gazziero DL. Procedimentos para instalação, avaliação e análise de experimentos com herbicidas. Londrina: Sociedade Brasileira da Ciência das Plantas Daninhas; 1995.
17. Ferreira DF. Sisvar: a computer statistical analysis system. Ciênc Agrotec. 2011;35(6):1039-42.
18. Ahmad Z, Khan SM, Ali S, Rahman IU, Ara H, Noreen I, et al. Indicator species analyses of weed communities of maize crop in district Mardan, Pakistan. Pak J Weed Sci Res. 2016;22(2):227-38.
19. Barros RE, Faria RM, Tuffi-Santos LD, Azevedo AM, Governici JL.

Physiological response of maize and weeds in coexistence. Planta Daninha. 2017;35:e017158134.

20. Raut VG, Khawale VS, Moharkar R, Bhadoriya R, Meshram D. Effect of different herbicides on weeds and grain yield of maize. J Soils Crops. 2017;27(1):248-52.

21. Santos SA, Tuffi-Santos LD, Sant'Anna-Santos BF, Tanaka FA, Silva LF, Santos A. Influence of shading on the leaf morphoanatomy and tolerance to glyphosate in *Commelina benghalensis* L. and *Cyperus rotundus* L. Aust J Crop Sci. 2015;9(2):135-42.

22. Dan HA, Procópio SO, Barroso AL, Dan LG, Oliveira AM Neto, Guerra N. Control of volunteer soybean plants with herbicides used in corn. Rev Bras Ciênc Agrár. 2011;6(2):253-7.

23. Costa LL, Almeida DP, Timossi PC, Santos TC, Bonifácio FD, Borges BD. Control of soybean RR voluntary in culture of corn with different doses and mixtures of herbicides. Rev Bras Herb. 2019;18:e655.

24. Alms J, Clay SA, Vos D, Moechnig M. Corn yield loss due to volunteer soybean. Weed Sci. 2016;64(3):495-500.

25. Galon L, Cavaletti DC, Giacomini JP, Silva AF, Bagnara MA, Toni JR, et al. Interference and economic threshold level of transgenic volunteer soybean plants in maize crop. Rev Bras Milho Sorgo. 2022;21:e1254.

26. Osipitan OA, Scott JE, Knezevic SZ. Tolpyralate applied alone and with atrazine for weed control in corn. J Agric Sci. 2018;10(10):32-9.

27. Sarangi D, Jhala AJ. Comparison of a premix of atrazine, bicyclopyrone, mesotrione, and S-metolachlor with other preemergence herbicides for weed control and corn yield in no-tillage and reduced-tillage production systems in Nebraska, USA. Soil Tillage Res. 2018;178:82-91

28. Barnes ER, Knezevic SZ, Lawrence NC, Irmak S, Rodriguez O, Jhala AJ. Preemergence herbicide delays the critical time of weed removal in popcorn. Weed Technol. 2019;33(6):785-93.

29. Alptekin H, Ozkan A, Gurbuz R, Kulak M. Management of weeds in maize by sequential or individual applications of pre- and post-emergence herbicides. Agriculture. 2023;13(2):421.

30. Cantu RM, Albrecht LP, Albrecht AJ, Silva AF, Danilussi MT, Lorenzetti JB. Herbicide alternative for *Conyza sumatrensis* control in pre-planting in no-till soybeans. Adv Weed Sci. 2021;39:e2021000025.

31. Osterholz WR, Dias JL, Grabber JH, Renz MJ. PRE-and POST-applied herbicide options for alfalfa interseeded with corn silage. Weed Technol. 2021;35(2):263-70.

32. Silva TS, Arneson NJ, DeWerff RP, Smith DH, Silva DV, Werle R. Preemergence herbicide premixes reduce the risk of soil residual weed control failure in corn. Weed Technol. 2023;37(4):410-21.

33. Vicensi T, Albrecht LP, Albrecht AJP, Silva AFM, Backes ML, Mundt TT. Mixtures of herbicides and time of application to control *Commelina benghalensis* in maize and off-season. Outlooks Pest Manag. 2024;35(2):81-8.

34. Souza MF, Henckes JR, Zobiole LH, Oliveira RS Junior, Braz GB, Constantin J, et al. Competitive response of maize against glyphosate-resistant *Digitaria insularis* and *Eleusine indica*. Crop Prot. 2024;183:e106760.

35. Langdon NM, Soltani N, Raedar AJ, Robinson DE, Hooker DC, Sikkema PH. Influence of adjuvants on the efficacy of tolpyralate plus atrazine for the control of annual grass and broadleaf weeds in corn with and without Roundup WeatherMAX®. Am J Plant Sci. 2020;11(3):465-95.

36. Galon L, Silva MR, Rossetto ER, Silva AF, Aspiazú I, Favretto EL, et al. Interaction between pesticides applied alone or in mixtures in corn. J Environ Sci Health B. 2021;56(11):986-93.

37. Armel GR, Richardson RJ, Wilson HP, Hines TE. Mesotrione and glufosinate in glufosinate-resistant corn. Weed Technol. 2008;22(4):591-6.