



Efficacy and selectivity of alternative herbicides to glyphosate on maize

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ABSTRACT

The aim was to evaluate the selectivity and weed control of herbicides atrazine, nicosulfuron, mesotrione and tembotrione, applied alone and associated, in post-emergence of maize. Were carried out two experiments, one in the field in a randomized complete block design with four replications and eleven treatments, the second in greenhouse in a completely randomized design, with four replications and ten treatments. The treatments were composed of isolated and associated herbicides. Treatments were applied V4 stage of plants. For first experiment, crop injury and control evaluations were performed, as well as variables related to agronomic performance (plant height, ear insertion height, prolificacy index, yield and mass of 1,000 grains) and mass of weeds. For second experiment, evaluations of crop injury, height, diameter and dry mass of plants were performed. The lower yield for experiment one was verified in the treatment where only mesotrione was applied, which was attributed to the lower control of monocotyledons weeds. Crop injury were observed at 21 DAA in both experiments, but not exceeding 7.5%. All treatments were considered selective to maize. The herbicides atrazine, nicosulfuron, mesotrione and tembotrione, at associations, were effective in the weed control, except the association atrazine + mesotrione.

Keywords: atrazine; nicosulfuron; mesotrione; tembotrione; *Zea mays* L.

INTRODUCTION

Maize (*Zea mays* L.) has high yield potential, which guarantees high yield in Brazil, mainly due to C4 metabolism and its physiological characteristics (Fancelli & Dourado Neto, 2000). In 2017/2018 season the total area sown with crop maize was 16,614.4 thousand hectares, with a yield of 4,857 kg per hectare and production of 80,709.5 thousand tons (Companhia Nacional de Abastecimento - Conab 2019).

Several factors interfere in the maize yield, among them weeds. In Brazil, several monocotyledons and eudicotyledons species are common in crops such as *Amaranthus* sp., *Cardiospermum halicacabum*, *Bidens* sp., *Euphorbia heterophylla*, *Ipomoea* sp., *Raphanus sativus*, *Richardia brasiliensis*, *Commelina benghalensis*, *Sida* sp., *Urochloa* sp., *Cenchrus*

echinatus, *Digitaria* sp., *Echinochloa* sp., *Eleusine indica* and *Panicum maximum* (Borém *et al.*, 2015). The chemical control is the main method used in the control of weeds and the herbicides are applied according to the time of application: pre-planting, pre-emergence and initial and late post-emergence (Oliveira Júnior, 2011).

With the advent of glyphosate-tolerant crops, the use of glyphosate herbicide was intensified. Correa & Alves (2009), Ramires *et al.* (2010), Oliveira Neto *et al.* (2013), among others, report their efficacy in weed control. However, with continued use of the herbicide glyphosate over the years, it has selected resistant weed biotypes.

In Brazil, there are 50 cases of weeds resistant to one or more herbicides belonging to one or more mechanisms of action. Of these, 8 species present resistance to glyphosate, 6 of them being verified in maize crop (Heap, 2019).

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To minimize problems caused by weeds, tolerant or resistant, Green (2012) and Riar *et al.* (2013) emphasize the importance of integrated weed management, which includes crop rotation and rotation of herbicide mechanisms of action. Besides that, Gazziero (2015) emphasizes the importance of further studies on the herbicide tank mixture, demonstrated in its work that 97% of the farmers make mixtures of more than one product per spray tank.

As herbicides alternative to glyphosate, used in post-emergence of maize, are applied atrazine, nicosulfuron, mesotrione, tembotrione and others, alone or in mixtures (Rodrigues & Almeida, 2018). Studies highlight the efficacy and/or selectivity of these herbicides in maize, however most often in association with glyphosate (Soltani *et al.*, 2010; Chahal *et al.*, 2018; Giovanelli *et al.*, 2018). There are few recent studies evaluating efficacy and/or selectivity of these herbicides, without association with glyphosate, in maize. This highlight the importance of studies of the efficacy and selectivity of the other herbicides, beyond glyphosate, used in the maize.

It is believed that atrazine, nicosulfuron, mesotrione and tembotrione, may be alternative herbicides to glyphosate for management of weeds in maize. The aim was to evaluate the selectivity and weed control of atrazine, nicosulfuron, mesotrione and tembotrione, applied alone and associated, in post-emergence of maize.

MATERIAL AND METHODS

Conditions and experimental design

Two experiments were carried out in the 2016/17 season, in the Piracicaba, state of São Paulo (SP), Brazil. Experiment I was conducted in the field (22°42'51.4"S 47°37'22.0"W), and the experiment II was conducted under greenhouse conditions (22°42'32.0"S 47°37'43.1"W).

The climate is characterized as Cwa (humid subtropical with drought in the winter) by the climatic classification of Köppen. Figure 1 shows the rainfall and temperature distribution throughout the period of conduction of the experiment I in the field.

Table 1 shows the chemical and physical analysis of the soil of the experimental area and the soil used to fill the pots of the experiment II in the greenhouse. Conventional maize hybrid 30F53, which has an early cycle, has been adapted for almost all regions of the country. Experiment I was installed in a fallow area, with soybean cultivation in the previous summer crop, conducted between December 2016 and March 2017.

The experimental design was a randomized complete block for experiment I and completely randomized for experiment II, with four replications and 11 treatments for experiment I (Table 2). The same

treatments herbicides were used for experiment II, with only one control treatment (without application). The application of the treatments was at the post-emergence of maize plants (V4 development stage), was used CO₂ pressurized spray, equipped with a bar with four nozzles, at a constant pressure of 200 kPa, providing an application volume of 200 Lha⁻¹ and velocity of 1 m s⁻¹, with the nozzles positioned at a height of 50 cm from the plants.

In the experiment I the experimental units were composed of parcels of 5 m in length and five rows of maize, with spacing between rows of 0.90 m, being considered useful area the three central lines, discarding the first and last meter of the parcel. In the experiment II, the experimental units were composed of 7 L pots filled with medium texture soil. Five seeds were sown per pot and after emergence, thinning was done leaving two plants per pot. It is noteworthy that for experiment II the experimental units were kept free from weed interference through weeding.

At the time of application, the field of the experiment I was under natural infestation of several weed species: *C. benghalensis*, *U. decumbens*, *Digitaria* sp., *E. heterophylla*, *Ageratum conyzoides*, *Bidens* sp., *Ipomoea* sp., and *Alternanthera tenella*.

Evaluations and data collection

The crop injury and weed control were evaluated by means of visual evaluations, in which percentages ranged from 0 to 100% in each experimental unit (where 0 represents no symptoms of injury and 100% death of plants), considering in this case symptoms significantly visible in the plants, according to their development (Velini *et al.*, 1995). These evaluations were performed for experiment I at 7, 14, 21, 28, 35 and 42 days after application (DAA). For the experiment II only the evaluation of crop injury at 7, 14, 21 and 28 DAA.

In the experiment I, at 42 DAA the shoot of remaining weeds of each plot was collected, with a square with an area of 0.25 m² (two replicates per plot). The material was dried in an oven with forced air ventilation for 72 h at 65°C and to measure the masses, an analytical balance was used with precision of three decimal places.

For experiment I, was performed evaluation of variables related to agronomic performance (plant height, ear insertion height, prolificacy index, yield and mass of 1,000 grains).

For the measurement of the variables: total plant height (from the soil surface to the insertion of the male inflorescence - tassel) and height of the ear insertion (from the soil surface to the ear insertion) were evaluated ten plants of the useful area per plot. A millimeter ruler was used, with the results expressed in meters.

For the determination of the prolificacy index, the number of ears per plants was counted, with the values obtained divided by 10, number of plants evaluated from the useful area of each parcel.

Yield estimation was carried out with the ear of the area of the plots manually harvested and threshed in a thresher for experiments, cleaned with the aid of sieves and placed in paper bags. The grains produced in each parcel had their weight measured and the moisture corrected to 13%, from these data the yield was calculated in $t\ ha^{-1}$. For the mass of one thousand grains the mass of two sub-samples per plot was measured and the moisture corrected to 13%.

For the experiment II, height evaluation was performed at 7, 14, 21 and 28 DAA. The two plants of each pot were measured, millimeter ruler was used, with results expressed in centimeters. At 28 DAA the shoot of each plant was

collected to measure the dry matter mass. For drying oven with forced ventilation was used for 72 h at 65 °C and to measure the masses, an analytical balance was used with precision of three decimal places.

Statistical analysis

It was performed analysis of variance by the F-test ($p < 0.05$) and the means of the treatments were compared by Tukey's (1949) test ($p < 0.05$) (Pimentel-Gomes & Garcia, 2002). For this purpose, the Sisvar 5.6 software was used (Ferreira, 2011). For crop injury, data were analyzed descriptively by percentage scale.

RESULTS

In the experiment I, at 7 DAA, injury was observed for nicosulfuron (6.8%), atrazine + nicosulfuron (5%) and mesotrione + nicosulfuron (6.3%) treatments. At 14 DAA

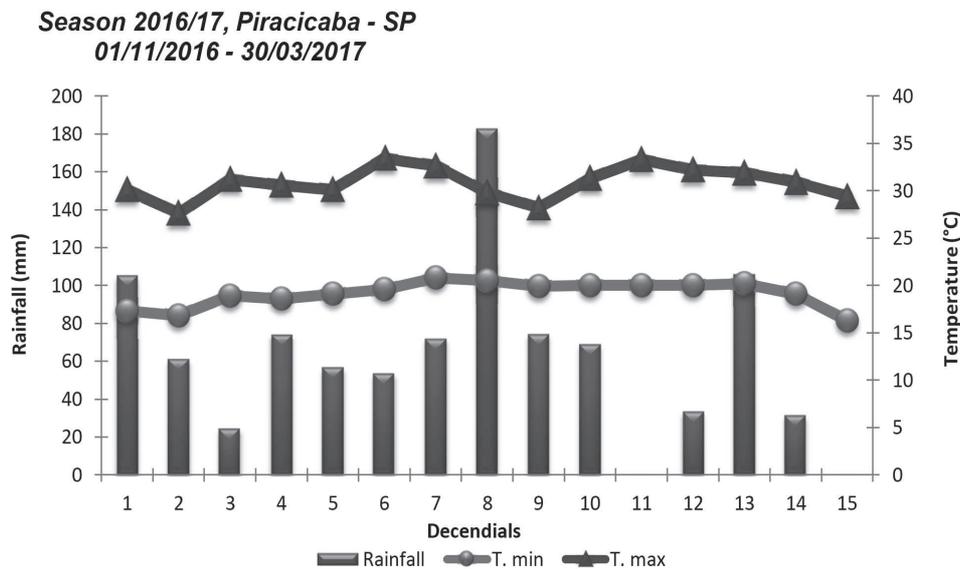


Figure 1: Representation of rainfall, minimum and maximum average temperature for the period referring to the maize crop cycle. Piracicaba - SP, 2016/17 season. Source: LEB - USP/ESALQ.

Table 1: Soil chemical and physical analysis of the experimental area, at depth of 0 to 20 cm. Piracicaba - SP, 2016/17 season

Experiment I									
pH (CaCl ₂)	Al	H + Al	P (resin)	K	Ca	Mg	SB	CEC	V
5.3	< 1.0	25.0	10.0	2.8	26.0	13	41.8	66.8	63
Clay			Silt			Sand			
41.0			5.0			54.0			
Experiment II									
pH (CaCl ₂)	Al	H + Al	P (resin)	K	Ca	Mg	SB	CEC	V
5.3	< 1.0	25.0	7.0	2.6	39.0	16	57.6	82.8	70
Clay			Silt			Sand			
40.0			6.0			54.0			

Units: Al, H + Al, K, Ca, Mg, SB and CEC ($mmol\ c\ dm^{-3}$); P (resin) ($mg\ dm^{-3}$); V, clay, silt and sand (%).

the scores were maintained for atrazine + nicosulfuron and mesotrione + nicosulfuron, whereas for nicosulfuron alone it increased to 7.5%; in this evaluation, 5% was also observed for atrazine + tembotrione treatment, which remained until 21 DAA. At 28, 35 and 42 DAA, no more symptoms of injury were observed in maize plants, for the application of all treatments (Table 3).

For experiment II, at 7 DAA, treatments that caused injury to maize plants were nicosulfuron (3.5%), tembotrione (3%) and atrazine + mesotrione + nicosulfuron (3.5%). At 14 DAA the score remained at 3% for tembotrione and reduced to 3% for the triple association. Whereas, at 21 DAA, the application that caused injury were atrazine + nicosulfuron (3%), mesotrione + nicosulfuron (4.5%), atrazine + tembotrione (3%), atrazine + nicosulfuron (3%) and mesotrione with a reduction to

3.5% (Table 4). Thus, the crop injury was found in experiment I and experiment II up to 21 DAA, after this evaluation no symptoms were observed in all treatments.

There were differences in the height in the experiment II at 7 DAA, for the treatment atrazine + mesotrione + nicosulfuron, with a lower value at 8.38 cm in relation to the control. At 28 DAA, the lowest values were for mesotrione, atrazine + nicosulfuron, mesotrione + nicosulfuron and for atrazine + mesotrione + nicosulfuron. However, to the shoot dry mass, there was no difference between the means in relation to the control (without application) (Table 5).

At 14, 21 and 28 DAA, atrazine + mesotrione + nicosulfuron, mesotrione + nicosulfuron, atrazine + tembotrione and atrazine + nicosulfuron provided the same weed control. At 7 DAA only the triple association was equal to the weed control, with control of 86.25%. On the other hand, treatments with isolated herbicides and the association atrazine + mesotrione resulted in lower control than weed control in all evaluations (Table 6).

The total dry mass of weeds was higher for atrazine (18.51 g), mesotrione (35.9 g) and atrazine + mesotrione (18.6 g) treatments, in which the highest dry mass was monocotyledons with 17.98, 26.61 and 17.17 g, respectively. However, for eudicotyledons weeds, the highest dry masses were observed in the treatments mesotrione (9.29 g), nicosulfuron (6.61 g) and tembotrione (3.76 g) (Table 7).

Maize yield was lower only when was applied mesotrione alone (Table 8), which can be explained by the low control of weeds, mainly monocotyledons.

DISCUSSION

Dan *et al.* (2011) also observed injury in maize hybrids submitted to nicosulfuron at rates of 50 and 60 g a.i. ha⁻¹

Table 2: Treatments composed by the isolated or associated application of herbicides, in post emergence of maize. Piracicaba - SP, 2016/17 season

Treatments	Rates ¹
control (with weeding)	-
control (without weeding)	-
atrazine	1,500
mesotrione	168
nicosulfuron	50
tembotrione	100.8
atrazine + mesotrione	1,500 + 168
atrazine + nicosulfuron	1,500 + 50
atrazine + tembotrione	1,500 + 100.8
mesotrione + nicosulfuron	168 + 50
atrazine + mesotrione + nicosulfuron	1,500 + 168 + 50

¹Grams of active ingredient per hectare (g a.i. ha⁻¹).

Commercial products: Gesaprin® GRDA (atrazine), Callisto® (mesotrione), Sanson® 40 SC (nicosulfuron), Soberan® (tembotrione).

Table 3: Evaluation of crop injury at 7, 14 and 21 days after application (DAA) of maize plants under isolated or associated application of herbicides (experiment I). Piracicaba - SP, 2016/17 season

Treatments	Crop injury (%)		
	7	14	21
control (with weeding)	0.0	0.0	0.0
control (without weeding)	0.0	0.0	0.0
atrazine	0.0	0.0	0.0
mesotrione	0.0	0.0	0.0
nicosulfuron	6.8	7.5	0.0
tembotrione	0.0	0.0	0.0
atrazine + mesotrione	0.0	0.0	0.0
atrazine + nicosulfuron	5.0	5.0	5.0
atrazine + tembotrione	0.0	5.0	5.0
mesotrione + nicosulfuron	6.3	6.3	2.5
atrazine + mesotrione + nicosulfuron	0.0	0.0	5.0
Mean	1.6	2.2	1.6

and in association of nicosulfuron + atrazine (20 + 1,500 and 40 + 3,000 g a.i. ha⁻¹) at 14 DAA. The symptoms varied from 2.33 to 5% in the lowest rate of nicosulfuron, reaching 7% in the highest rate, agreeing with the verified in this work where the scores ranged from 6.75% at 7 DAA and 7.5% at 14 DAA. The authors attributed scores up to 2.33% in the lowest rates and up to 3% in the highest rates applied to the 14 DAA, for the associations. These scores are being close to those found in this study, in which the scores were up to 5%, but with the hybrid different from that studied.

Weed control with atrazine (2,400 g a.i. ha⁻¹) and mesotrione (192 g a.i. ha⁻¹) isolated were studied by Philippi *et al.* (2016), that observed control of 58.75% and 32.5% for atrazine and mesotrione, respectively. The control may have been compromised due to the climatic

conditions of high temperatures and low relative air humidity, reducing the effectiveness of the herbicides and raising the seed bank in the later crop, in which, they verified controls of 89.2% for atrazine and 85.6% for mesotrione.

In a study by Brown *et al.* (2016), the use of atrazine (1,500 g a.i. ha⁻¹) for *Conyza canadensis* (eudicotyledon weed) resulted in a control of 48% in the evaluation of 8 weeks after application, when in association with the mesotrione the control reached 97%. As in this study, that the control with atrazine alone was 46.25% and 10% for mesotrione at 42 DAA. However, in this study, the weed control with atrazine + mesotrione resulted in efficacy of only 45%, which is explained by the high presence of monocotyledons weeds, with dry mass of 26.61 g.

Table 4: Evaluation of crop injury at 7, 14, 21 and 28 days after application (DAA) of maize plants under isolated or associated application of herbicides (experiment II). Piracicaba - SP, 2016/17 season

Treatments	Crop injury (%)		
	7	14	21
control	0.0	0.0	0.0
atrazine	0.0	0.0	0.0
mesotrione	0.0	0.0	0.0
nicosulfuron	3.5	0.8	0.0
tembotrione	3.0	3.0	0.0
atrazine + mesotrione	3.0	3.0	0.0
atrazine + nicosulfuron	0.0	3.0	0.0
atrazine + tembotrione	0.0	3.0	0.0
mesotrione + nicosulfuron	0.0	4.5	3.5
atrazine + mesotrione + nicosulfuron	3.5	3.0	0.0
Mean	1.3	2.0	0.4

Table 5: Height and dry mass of shoot of maize plants under isolated or associated application of herbicides (experiment II). Piracicaba - SP, 2016/17 season

Treatments	Height (cm)				Shoot
	7	14	21	28	dry mass (g)
control	29.63 a	39.75	59.75	85.13 ab	38.91
atrazine	24.88 ab	46.13	61.63	86.13 ab	42.24
mesotrione	22.50 ab	40.38	43.50	73.75 d	38.04
nicosulfuron	22.88 ab	41.63	55.88	89.38 a	41.08
tembotrione	27.50 ab	44.88	55.25	84.50 ab	42.15
atrazine + mesotrione	23.25 ab	38.38	51.50	87.75 ab	43.24
atrazine + nicosulfuron	25.50 ab	41.75	56.25	81.00 bc	35.98
atrazine + tembotrione	23.13 ab	38.50	49.88	75.50 cd	36.38
mesotrione + nicosulfuron	24.63 ab	43.88	59.63	91.00 a	43.61
atrazine + mesotrione + nicosulfuron	21.25 b	39.25	44.25	74.50 cd	32.83
Mean	24.51	41.45	53.75	82.86	39.34
CV (%)	12.44	11.04	18.04	3.49	13.58
F	2.70*	0.95 ^{ns}	1.01 ^{ns}	0.59*	0.42 ^{ns}

* Means followed by the same letter in the column do not differ statistically from each other by the Tukey's (1949) test ($p < 0.05$). ns - not significant, means do not differ statistically from each other by the F-test ($p < 0.05$).

The weed control in conventional maize with nicosulfuron (35 g a.i. ha⁻¹) in V4 stage, sequential application of nicosulfuron (35 g a.i. ha⁻¹) in V4 and V6 and nicosulfuron (35 g a.i. ha⁻¹) + metolachlor (1,120 g a.i. ha⁻¹) in V4, resulted in 61, 66 and 68% control, respectively. The use of residual herbicides is necessary to obtain better results (Burke *et al.*, 2008). In the present study, although nicosulfuron did not cause symptoms of injury after 21 DAA, the control percentage reached a maximum of 80% (21 DAA).

Janak & Grichar (2016) studied the use of herbicides, at pre-emergence, to control monocotyledons and

eudicotyledons weeds in maize. The authors found at 42 DAA that control for *Brachiaria reptans* was 40% when using atrazine, 93% for s-metolachlor and 82% when both herbicides were associated. They also verified 90% control for this species when they associated s-metolachlor + atrazine + mesotrione. In addition, all treatments used resulted in injury symptoms of less than 3% and did not affect crop yield.

The control of *E. crus-galli*, *Urochloa ramosa* and *I. hederacea* with tembotrione (92 g a.i. ha⁻¹) was 86, 84 and 87%, respectively, at 28 DAA. In the treatments with atrazine (2,240 g a.i. ha⁻¹) were 80, 78 and 95% to the same

Table 6: Weed control at 7, 14, 21, 28, 35 and 42 days after application (DAA) of maize plants under isolated or associated application of herbicides (experiment I), Piracicaba - SP, 2016/17 season

Treatments	Control (%)					
	7	14	21	28	35	42
control (with weeding)	100.00 a	100.00 a	100.00 a	100.00 a	100.00 a	100.00 a
control (without weeding)	0.00 h	0.00 f	0.00 e	0.00 e	0.00 d	0.00 e
atrazine	66.25 def	63.75 cd	58.75 c	55.00 d	50.00 c	46.25 d
mesotrione	41.25 g	40.00 e	35.00 d	20.00 e	10.00 d	10.00 e
nicosulfuron	68.75 cde	71.25 bc	80.00 b	78.75 bc	78.75 b	70.00 bc
tembotrione	53.75 efg	51.25 de	53.75 cd	58.75 cd	61.25 c	61.25 cd
atrazine + mesotrione	51.25 fg	53.75 cde	53.75 cd	46.25 d	45.00 c	45.00 d
atrazine + nicosulfuron	77.50 bcd	85.00 ab	88.75 ab	90.00 ab	92.50 ab	89.25 ab
atrazine + tembotrione	83.75 bc	89.25 ab	91.75 ab	92.25 ab	92.25 ab	90.75 ab
mesotrione + nicosulfuron	77.50 bcd	85.00 ab	90.00 ab	90.00 ab	87.50 ab	86.25 ab
atrazine + mesotrione + nicosulfuron	86.25 ab	95.00 a	95.50 ab	96.00 ab	96.50 ab	96.00 ab
Mean	64.20	66.75	67.93	66.10	64.88	63.16
CV (%)	10.04	11.55	11.87	12.65	10.56	12.87
F	53.55*	51.36*	50.05*	49.22*	68.13*	49.06*

* Means followed by the same letter in the column do not differ statistically from each other by the Tukey's (1949) test ($p < 0.05$).

Table 7: Shoot dry mass of weeds monocotyledons, eudicotyledons and total under isolated or associated application of herbicides (experiment I), Piracicaba - SP, 2016/17 season

Treatments	Dry mass (g)		
	MONO ¹	EUDI ¹	Total
control (with weeding)	0.00 a	0.00 a	0.00 a
control (without weeding)	25.33 bc	18.30 f	43.63 c
atrazine	17.98 b	0.53 ab	18.51 b
mesotrione	26.61 c	9.29 e	35.90 c
nicosulfuron	2.09 a	6.61 d	8.70 a
tembotrione	1.64 a	3.76 b	5.40 a
atrazine + mesotrione	17.17 b	1.43 ab	18.60 b
atrazine + nicosulfuron	2.06 a	1.04 ab	2.24 a
atrazine + tembotrione	0.77 a	1.42 ab	2.19 a
mesotrione + nicosulfuron	0.17 a	2.07 bc	2.24 a
atrazine + mesotrione + nicosulfuron	0.86 a	0.61 ab	1.47 a
Mean	8.60	4.09	12.62
CV (%)	14.39	7.71	11.88
F	13.38*	8.12*	11.02*

¹ MONO – monocotyledons. EUDI – eudicotyledons.

* Means followed by the same letter in the column do not differ statistically from each other by the Tukey's (1949) test ($p < 0.05$).

Table 8: Agronomic performance variables of maize plants under isolated or associated application of herbicides (experiment I). Piracicaba - SP, 2016/17 season

Treatments	PH	EH	PI	YIELD ^a	GM
control (with weeding)	2.38	1.35	1.20	10.89 a	271.03
control (without weeding)	2.35	1.35	1.40	7.91 b	279.86
atrazine	2.42	1.40	1.10	9.14 ab	279.86
mesotrione	2.33	1.35	1.25	7.85 b	266.87
nicosulfuron	2.33	1.37	1.28	9.16 ab	273.44
tembotrione	2.38	1.35	1.28	8.40 ab	276.06
atrazine + mesotrione	2.39	1.38	1.25	9.60 ab	265.10
atrazine + nicosulfuron	2.33	1.37	1.50	10.53 a	290.31
atrazine + tembotrione	2.40	1.37	1.20	10.79 a	282.57
mesotrione + nicosulfuron	2.32	1.34	1.28	10.11 ab	296.89
atrazine + mesotrione + nicosulfuron	2.41	1.37	1.23	10.80 a	281.21
Mean	2.37	1.36	1.27	9.56	277.34
CV (%)	3.60	3.33	14.90	11.15	6.27
F	0.71 ^{ns}	0.61 ^{ns}	1.29 ^{ns}	4.71*	1.35 ^{ns}

PH - plant height (m), EA - ear insertion height (m), PI - prolificacy index (plant ears⁻¹), YIELD (t ha⁻¹), GM - 1,000 grains mass (g).

* Means followed by the same letter in the column do not differ statistically from each other by the Tukey's (1949) ($p < 0.05$). ns - not significant, means do not differ statistically from each other by the F-test ($p < 0.05$).

species. When the two herbicides were associated, the control obtained was 94, 92 and 96%. It was verified control of 43% for *Sorghum halepense* when only tembotrione was used and 39% for the application of atrazine isolated, but in the combination of herbicides this control was 73%. For *A. palmeri*, the two isolated or associated herbicides obtained controls above 92% (Stephenson IV *et al.*, 2015). As in this work, the use of tembotrione and its association with atrazine did not reduce maize yield.

Several studies highlight the efficacy of glyphosate, in different associations, for weed control in maize, with control of different weeds around 90% (Patches *et al.*, 2017; Chahal *et al.*, 2018; Chahal & Jhala, 2018; Kaur & Jhala, 2018). This same control level was observed in this study for the application of atrazine + nicosulfuron, atrazine + tembotrione, mesotrione and nicosulfuron + atrazine + nicosulfuron + mesotrione without the use of glyphosate.

These results indicate that in certain situations effective weed management in maize is possible even without glyphosate. This herbicide is very important in different crops for weed control, but the characterization of alternative treatments is very important in the management and prevention of selection of glyphosate-resistant biotypes. As highlighted by several studies, management with alternative herbicides to glyphosate is necessary to assist in the management of herbicide resistance to weed resistance (Heap & Duke, 2018; Neve *et al.*, 2018; Rosario-Lebron *et al.*, 2019).

In addition, the associations help in effective control, mainly of monocotyledons, helping to maintain the maize yield, as observed in this study. Other studies also highlight the importance of using glyphosate alternative herbicides in maize, highlighting atrazine and/or nicosulfuron (Ganie *et al.*, 2017; Chahal & Jhala, 2018; Galon *et al.*, 2018).

CONCLUSIONS

The post-emergence (V4) application of atrazine, nicosulfuron, mesotrione and tembotrione, applied alone and associated was selective to the conventional maize hybrid 30F53.

The herbicides atrazine, nicosulfuron, mesotrione and tembotrione, at associations, were effective in the weed control, except the association atrazine + mesotrione.

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