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Evaluation of herbicides applied on sugar cane during rainy season in Brazil

Avaliação de herbicidas aplicados em cana-de-açúcar durante estação chuvosa no Brasil

Carlos Alberto Mathias Azania[1*], Ana Regina Schiavetto[2], Fabrício Simone Zera[3], Cássia Morilha Lorenzato [4], Andréa Aparecida Mathias Azania[5], Alan Borges[6]

Abstract - This research aimed to study different herbicides applied in the sugarcane culture during the rainy season. The experiment was established in a 3rd ratoon crop of cultivar SP84-2025 and planted in a soil with 49.9% clay, 36.6% sand and 13.5% silt. The experimental design was a randomized block in a split-plot scheme with experimental units consisting of five sugarcane interrows with 5 m, spaced 1,5 m (37.5 m^2) and sub-plots with one cane row of 5 m (7.5 m^2). Seeds of *Ipomoea quamoclit, Ipomoea hederifolia, Merremia cissoides, Panicum maximum* and *Brachiaria decumbens* were sown in the sub-plots and untreated control. The herbicides evaluated were imazapic (147 g ha^{-1}), imazapic (98 g ha^{-1}) + sulfentrazone (600 g ha^{-1}), sulfentrazone (800 g ha^{-1}), tebuthiuron (1000 g ha^{-1}), amicarbazone (1400 g ha^{-1}), flumioxazin (125 g ha^{-1}), diuron (1066 g ha^{-1}) + hexazinone (134 g ha^{-1}) + imazapic (98 g ha^{-1}), amicarbazone (840 g ha^{-1}) + isoxaflutole (82.5 g ha^{-1}), imazapic (98 g ha^{-1}) + isoxaflutole (85 g ha^{-1}) and applied at pre-emergence of the crop and weeds. During the 120 days following spraying, 698.7 mm of rainfall was observed, the average minimum and maximum temperature being 21.9 and 30.6 °C, respectively. The herbicides that were more persistent and better control on the species studied in the following descending order: amicarbazone (91.2% control), imazapic (90.8%), imazapic + sulfentrazone (89.6%), amicarbazone + isoxaflutole (89.2%), imazapic + isoxaflutole (85.6%), diuron + hexazinone + imazapic (84.4%), tebuthiuron (76%), sulfentrazone (70.8%), flumioxazin (19.2%).

Keywords: Weeds, trash, *Saccharum* spp., humidity.

Resumo - O trabalho objetivou estudar diferentes herbicidas aplicados na cultura da cana-de-açúcar durante a estação chuvosa. O experimento foi instalado em soqueira de 3° corte de cana-de-açúcar, cv SP84-2025, em solo com 49,9% de argila, 36,6% de areia e 13,5% de silte. O delineamento foi em blocos casualizados em esquema de parcelas sub-divididas, sendo as unidades experimentais constituídas por 5 entre linhas da cultura, com 5 m, espaçadas em 1,5 m (37,5 m^{-2}) e as sub-parcelas com uma entre linha de 5 m (7,5m^{-2}). As sementes de *Ipomoea quamoclit, Ipomoea hederifolia, Merremia cissoides, Panicum maximum* e *Brachiaria decumbens* foram semeadas nas sub-parcelas e nas testemunhas. Os herbicidas avaliados foram:

[1]* PqC Dr Instituto Agronômico/Centro de Cana, Rod. Anel Viário contorno sul, km 321, CP 206, CEP 14.001-970, Ribeirão Preto, SP. e-mail: azania@iac.sp.gov.br
[2] Mestranda da FCAV/ UNESP, Genética e Melhoramento de Plantas.
[3] Eng. Agr. Mestrando em Agricultura Tropical e Subtropical, Instituto Agronômico.
[4] Bolsista PIBIC do Instituto Agronômico.
[5] PqC Dra Voluntária do Instituto Agronômico/Centro de Cana
[6] Eng. Agr. BASF do Brasil S/A.

imazapic (147 g ha^{-1}); imazapic (98 g ha^{-1})+sulfentrazone (600 g ha^{-1}); sulfentrazone (800 g ha^{-1}); tebuthiuron(1000 g ha^{-1}); amicarbazone (1400 g ha^{-1}); flumioxazin(125 g ha^{-1}); diuron (1066 g ha^{-1})+hexazinone (134 g ha^{-1})+imazapic (98 g ha^{-1}); amicarbazone (840 g ha^{-1})+ isoxaflutol (82,5 g ha^{-1}); imazapic (98 g ha^{-1})+isoxaflutol (85 g ha^{-1}) e aplicados em pré-emergência das plantas daninhas e cultura. Após 120 dias da aplicação foram observados 698,7 mm de chuva, apresentando temperatura média de 21,9 e 30,6°C para temperatura mínima e máxima, respectivamente. Os herbicidas que apresentaram maior persistência em relação às intempéries e melhor controle sobre as espécies estudadas foram na seguinte ordem decrescente: amicarbazone (91,2%), imazapic (90,8%), imazapic + sulfentrazone (89,6%), amicarbazone + isoxaflutol (89,2%), imazapic + isoxaflutole (85,6%), diuron + hexazinone + imazapic (84,4%), tebuthiuron (76%), sulfentrazone (70,8%), flumioxazin (19,2%).
Palavras chave: Plantas daninhas, palha, *Saccharum* spp., umidade.

Introduction

Among main weeds emerging in sugar cane fields harvested in green in the Ribeirão Preto area, those from the genus *Ipomoea* and *Merremia* are predominates, as well as some belonging to the Poaceae family (Azania et al., 2002). These plants may interfere with cultural practices, especially during mechanized harvest both by reducing the harvesting operational efficiency and to the fact that the plants are involved in the crop culms (Elmore et al., 1990).

There are different selective herbicides and with an action scope on different weeds (MAPA, 2008), but regardless the weed flora present, most pre-emergence herbicides used require soil humidity for its molecules to move through the soil solution and be absorbed by the weed seeds (Martini & Durigan, 2004). Thus, chemical weed control is more effective when performed during the rainy season, as the water available in the soil and the intense development of weeds favor herbicides absorption.

Concerning *Ipomoea* spp., the most common method to control is the chemical control, which, is usually conducted in pre-emergence in early spring (Siebert et al., 2004). During this period, the more intense rainfall associated to high temperatures may cause faster degradation of residual herbicides in soil (Viator et al., 2002). The efficacy of weed control with soil residual herbicides, both in the rainy and in the dry season of the year, is influenced by soil moisture, clay and organic matter contents, pH and by soil coverage with straw, as well by herbicides physical-chemical characteristics, such as solubility and vapour pressure. Those factors may also influence adsorption, leaching and biological degradation processes, with a consequent reflection on the persistence of those compounds in the soil and on the absorption by weed roots (Walker et al., 1992).

The persistence of some herbicides in the soil is extremely variable. Some herbicides may be degraded within few days, while others may persist for several months or years; however, the time that they remain active in the soil depends on edaphoclimatic conditions (Silva et al., 1999).

Within this context, the objective of this work was to evaluate the agronomic effectiveness of different herbicides subject to the weather of the rainy season in the sugarcane culture.

Material And Methods

The experiment was established under field conditions in a sugar cane plantation (at Serrana, SP) in its third ratoon. The cane variety was SP84-2025 and it was planted at a row spacing of 1.50 m. The soil type in the area was a Red Latosol, with 49.9% clay, 36.6% sand and 13.5% silt. Previous soil chemical analysis reported organic matter 0-20 cm depth layer (31 g dm^{-3}), pH (5,3), Al^{+3} (1 $mmol_c.dm_{-3}$), H+Al (31 $mmol_c.dm_{-3}$) and V% (61.2%).

The experimental design was a split-plot scheme, with the main plots composed of five sugar cane interrows of 5 m long each, representing an useful area of 37.5 m^2, and the sub-plots by each interrow with 7.5 m^2 of useful area. The herbicides (Table 1) were assigned to the main-plots and the each weed species were sowed to the sub-plots: *Ipomoea quamoclit, Ipomoea hederifolia, Merremia cissoides, Panicum maximum* and *Brachiaria decumbens*.

Table 1 – Herbicides and doses in this experiment. Ribeirão Preto/SP, 2009.

Treat.	**Herbicides**	
	Active ingredients (g ha^{-1})	**Commercial brand (g or L ha^{-1})**
T1	untreated	-
T2	imazapic (147)	Plateau (210 g)
T3	imazapic (98) + sulfentrazone (600)	Plateau (140 g) + Boral (1.2 L)
T4	sulfentrazone (800)	Boral (1.6 L)
T5	tebuthiuron (1000)	Combine (2.0 L)
T6	amicarbazone (1400)	Dinamic (2000 g)
T7	flumioxazin (125)	Flumizyn (250 g)
T8	[diuron (1066) + hexazinone (134)] + imazapic (98)	Advance (2000 g) + Plateau (140)
T9	amicarbazone (840) + isoxaflutole (82.5)	Dinamic (1200 g) + Provence (110 g)
T10	imazapic (98) + isoxaflutole (85)	Plateau (140 g) + Provence (110 g)

[ ] indicate formulated mixtures.

The seeds were sown on 16 September 2008 in the interrows of each plot. During sowing, the cane straw was removed, the seeds were sown and the straw returned to the plots. The amount of seeds used was related to the germination test provided by the seed supplying company, in such a way that for each species an expected 100 plants were sown to each main-plot. Thus, in split-plots with *I. hederifolia*, 6 g of seeds were sown, in the ones with *I. quamoclit*, 9 g seeds; *Merremia cissoides*, 7 g; *Panicum maximum*, 3 g and *Brachiaria decumbens*, 4 g.

Herbicides application was performed on September 17, 2008 in pre-emergence of both weeds and sugar cane with a pressurized backpack sprayer equipment regulated at 200 kPa pressure and 250 L ha^{-1} spray volume. The application started at 3:20 p.m. at a temperature of 30.1°C, relative humidity 37.5%, wind gusts between 5 and 6 km h^{-1}, sky with 40% nebulosity, and was concluded at 4:40 p.m. with average air temperature 29.4°C, relative humidity 39%, wind gusts up to 2.8 km h^{-1} and 40% nebulosity.

At 70, 90 and 120 days after application (DAA), weed control by herbicides treatments were assessed. The methodology used was assigning percentage scores to the coverage of weeds in the main-plot area, with 0 for no infestation and 100% for total infestation. Those scores were used for assigning control based on the calculation: ctrl=100-%specific coverage. To make the control scores assigned more practical, EWRC (1964) proposal, adapted by Rolim (1989), was used as shown in Table 2.

The control scores were submitted to variance analysis according to the design proposed, and transformed to arc sen $\sqrt{x+0,5}$ /100). The means were compared by Tukey test at 5% probability.

Table 2 – Weed control percentage assessment and classification (Rolim, 1989).

% OF CONTROL	ASSESSMENT
99.1-100.0	Excellent (E)
96.6-99.0	Very good (VG)
92.6-96.5	Good (G)
85.1-92.5	Sufficient (S)
75.1-85.0	Doubtful (D)
60.1-75.0	Insufficient (I)
40.1-60.0	Poor (P)
15.1-40.0	Very Poor (VP)
00.0-15.0	No effect (NO)

Results And Discussion

From the establishment of experiment at September 2008 up to the last assessment (01/16/09), a total of 698.7 mm of rain was recorded and during the same period, minimum and maximum average temperatures were 21.9 and 30.6°C with the weed species seeds exposed to (average) oscillation of 8.7°C daily (Table 3). The herbicides applied were possibly exposed over the straw layer for at least 15 days, as at the end of that period, an accumulation of 26.1 mm rain was recorded, possibly enough for herbicides to be leached through the straw layer and reach the soil.

The assessments were possible only from 70 DAA as there were no weeds in the plots prior to that date. Some weeds started emerging over the straw layer after 60 DAA, but infestation was insufficient for a proper assessment.

Table 3 – Rainfall and average temperatures occurring during experiment assessment period. Ribeirão Preto/SP, 2009.

	Months	Rainfall (mm)	Mean Minimum temperature (°C)	Mean Maximum temperature (°C)
2008				
	September*	10.3	25.9	30.3
	October	80.9	21.4	32.3
	November	157.1	20.7	30.8
	December	265.8	20.9	29.8
2009	January*	184.6	20.4	29.9
		698.7 (accumulated)	21.9 (average)	30.6 (average)

Source: Instituto Agronômico/Centro de Cana; [1/]data from herbicides application (09/19/08); [2/]data up to the last assessment (01/16/2009).

At 70 DAA , except for flumioxazin (125 g ha^{-1}), which provided insufficient control (73%), all the other herbicides provided control rated from sufficient (88.8) to excellent (100) in relation to the infesting community sown (Table 4). However, there is little information available related to flumioxazin efficacy concerning weeds that are important in tropical agriculture (Jaremtchuk et al., 2009).

At 70 DAA, among the weed species, *I. quamoclit* was the best-controlled species (96.11%). In that assessment, it may be more accurately observed, by variance analysis (Table 5), that all weed species were controlled by the herbicides in levels rated between sufficient (85%) and excellent (100%). Exceptions were observed for flumioxazin (125 g ha^{-1}) for Convolvulaceae species, sulfentrazone for *M. cissoides* and *P. maximum* species, and tebuthiuron for *P. maximum* species.

At 90 DAA, no significant changes occurred as compared to the first assessment. Flumioxazin (125 g ha^{-1}) still provided the lowest control level (65.88%) over the weeds sown in this study, considered insufficient in practice. *I. quamoclit* was still the best controlled weed (95.93%) similar to *M. cissoides* (90.15%) (Table 4). However, a closer look at the level of control provided by each herbicide treatment on individual species, show that sulfentrazone still provided unsatisfactory control for *M. cissoides* and *P. maximum*, and tebuthiuron for species *P. maximum* (Table 5) at 90 DAA. Flumioxazin also started to demonstrate poor control at 90 DAA.

At 120 DAA, more marked changes were observed with respect to the control provided by the different herbicide treatments (Table 4). In addition to flumioxazin (125 g ha^{-1}), sulfentrazone (800 g ha^{-1}), tebuthiuron (1000 g ha^{-1}) and [diuron+hexazinone, 1066+134 g ha^{-1}]+imazapic (98 g ha^{-1}) also provided unsatisfactory level of control on weeds.

All species were poorly controlled by herbicides when compared to previous assessments. However, it was observed that all herbicides provided unsatisfactory control for at least one species (Table 5); imazapic (147 g ha^{-1}) provided unsatisfactory control only for *B. decumbens*; imazapic (98 g ha^{-1}) + sulfentrazone (600 g ha^{-1}) on *M. cissoides*, sulfentrazone (800 g ha^{-1}) on *M cissoides*, *P. maximum* and *B. decumbens*; tebuthiuron (100 g ha^{-1}) on *P. maximum* and *B. decumbens*; amicarbazone (1400 g ha^{-1}) on *I. quamoclit* and *B. decumbens*, flumioxazin (125 g ha^{-1}) provided unsatisfactory control for all the species, diuron (1066 g ha^{-1}) + hexazinone (134 g ha^{-1}) + imazapic (98 g ha^{-1}) on *I. quamoclit*, *M. cissoides* and *B. decumbens*; amicarbazone (840 g ha^{-1}) + isoxaflutole (82.5 g ha^{-1}) on *I. hederifolia* and imazapic (98 g ha^{-1}) + isoxaflutole (85 g ha^{-1}) on *I. quamoclit* and *B. decumbens*.

Regardless the rain intensity, imazapic has good performance on sedges, both in the absence and in the presence of straw, while for sulfentrazone, the presence of 20 t ha^{-1} sugar cane straw decreased the herbicide efficacy (Simoni et al., 2006).

Conclusions

At 120 days after application, during which 698.7 mm rain were recorded with averages of 21.9 and 30.6°C as minimum and maximum temperature respectively, the herbicides that persisted to weather and provided control over the species studied were in the following order: sufficient control: imazapic, amicarbazone, imazapic + sulfentrazone, imazapic + isoxaflutole amicarbazone + isoxaflutole; doubtful control: diuron + hexazinone + imazapic, tebuthiuron;

insufficient control: sulfentrazone; and very poor control: flumioxazin.

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Table 4 – Percentage of control provided by different herbicides over the infesting community and general control provided by herbicides over each species studied. Ribeirão Preto/SP, 2009.

Variation causes	Control (DAA)					
	70		90		120	
Herbicides (A)	**orig.**	**transf.**	**orig.**	**transf.**	**orig.**	**transf.**
imazapic (147 g ha^{-1})	100.00 (E)	90.00 a	98.13(VG)	87.90 a	90,80(S)	78,53 a
imazapic (98 g ha^{-1}) + sulfentrazone (600 g ha^{-1})	97.60 (VG)	86.96 a	97.07(VG)	85.86 a	89,60(S)	79,39 a
sulfentrazone (800 g ha^{-1})	88.80 (S)	78.78 a	89.74(S)	79.54 a	74,80(I)	67,24 a
tebuthiuron (1000 g ha^{-1})	92.20 (S)	80.34 a	92.54(S)	81.70 a	76,00(D)	67,86 a
amicarbazone (1400 g ha^{-1})	99.40 (E)	88.84 a	98.14(VG)	87.39 a	91,20(S)	81,00 a
flumioxazin (125 g ha^{-1})	73.00 (I)	62.28 b	65.88 (I)	57.15 b	27,20(P)	29,63 b
diuron (1066 g ha^{-1})+hexazinone (134 g ha^{-1}) + imazapic (98 g ha^{-1})	98.00 (VG)	86.87 a	98.00(VG)	86.87 a	84,40(D)	74,83 a
amicarbazone (840 g ha^{-1}) + isoxaflutole (82,5 g ha^{-1})	99.00 (VG)	88.50 a	98.13(VG)	87.01 a	89,20(S)	79,47 a
imazapic (98 g ha^{-1}) + isoxaflutole (85 g ha^{-1})	98.80 (VG)	88.27 a	97.07(VG)	86.11 a	85,60(S)	76,35 a
Untreated (%)	47.00		51.71		93.60	
Species (B)						
Ipomoea hederifolia	95.11	84.57 ab	94.30	83.93 ab	85.11	76.39 a
Ipomoea quamoclit	96.11	85.33 a	95.93	85.15 a	80.44	71.11 ab
Merremia cissoides	89.56	80.02 b	90.15	81.00 ab	81.56	74.32 a
Panicum maximum	94.67	84.15 ab	91.56	81.57 ab	76.44	67.99 ab
Brachiaria decumbens	95.00	83.06 ab	91.78	79.19 b	70.22	62.58 b
F (plot)	9.98 **		10.65**		11.91 **	
CV (%-plot)	16.77		18.28		33.11	
F(split-plot)	2.55 *		2.80 *		4.52 **	
CV (% split-plot)	10.43		11.61		24.40	
Interaction (A) x (B)	2.83 **		2.68 **		2.67 **	

DAA (days after application); orig. (original data in %); transf. (data transformed to arc sen $\sqrt{x+0,5}$ /100); D=doubtful; P=poor; S= sufficient G= good; E= excellent and VG=very good.

Table 5 – Specific weed control provided by herbicides at 70, 90 and 120 DAA. Ribeirão Preto/SP, 2009.

	Untreated (%) –T1	Variables	Herbicides (A)								
		Species (B)	T2	T3	T4	T5	T6	T7	T8	T9	T10
70 DAA	70.00	*I. hederifolia*	90.00 Aa (100 E)	84.83 Aa (96 G)	90.00 Aa (100 E)	86.51 Aba (98 VG)	90.00 Aa (100 E)	54.99 Bb (66 I)	90.00 Aa (100 E)	84.83 Aa (96 G)	90.00 Aa (100 E)
	49.00	*I. quamoclit*	90.00 Aa (100 E)	90.00 Aa (100 E)	90.00 Aa (100 E)	90.00 Aa (100 E)	86.51 Aa (98 VG)	58.90 ABb (72 I)	84.83 Aa (96 VG)	87.69 Aa (99 VG)	90.00 Aa (100 E)
	60.00	*M. cissoides*	90.00 Aa (100 E)	79.99 Aab (92 S)	62.00 Cbc (68 I)	81.34 ABCab (94 G)	90.00 Aa (100 E)	50.38 Bc (54 P)	86.51 Aa (98 VG)	90.00 Aa (100 E)	90.00 Aa (100 E)
	34.00	*P. maximum*	90.00 Aa (100 E)	90.00 Aa (100 E)	72.26 BCa (84 I)	71.15 Ca (81 D)	90.00 Aa (100 E)	73.92 Aa (87 S)	90.00 Aa (100 E)	90.00 Aa (100 E)	90.00 Aa (100 E)
	22.00	*B. decumbens*	90.00 Aa (100 E)	90.00 Aa (100 E)	79.66 Aba (92 S)	72.68 BCa (88 S)	87.69 Aa (98 VG)	73.15 Aa (86 S)	83.02 Aa (96 G)	90.00 Aa (100 E)	81.34 Aa (94 G)
90 DAA	73.29	*I. hederifolia*	90.00 Aa (100 E)	84.83 Aa (96 G)	90.00 Aa (100 E)	87.25 Aba (98.67 VG)	90.00 Aa (100 E)	50.73 AB (58.68 P)	90.00 Aa (100 E)	82.59 Aa (95.34 G)	90.00 Aa (100 E)
	39.31	*I. quamoclit*	90.00 Aa (100 E)	90.00 Aa (100 E)	90.00 Aa (100 E)	90.00 Aa (100 E)	83.92 Aa (94.68 G)	59.43 ABb (72.69 I)	86.51 Aa (98 VG)	86.51 Aa (98 G)	90.00 Aa (100 E)
	62.65	*M. cissoides*	90.00 Aa (100 E)	79.99 Aab (92 S)	64.96 Cbc (72.68 I)	90.00 Aa (100 E)	90.00 Aa (100 E)	47.46 Bc (48.68 P)	86.51 Aab (98 VG)	90.00 Aa (100 E)	90.00 Aa (100 E)
	46.65	*P. maximum*	90.00 Aa (100 E)	90.00 Aa (100E)	70.67 BCab (81.34 D)	70.05 Cab (76.68 D)	86.51 Aa (98 VG)	61.00 ABb (70.68 I)	90.00 Aa (100 E)	85.95 Aa (97.33 G)	90.00 Aa (100 E)
	36.65	*B. decumbens*	79.52 Aab (90.67 S)	84.49 Aab (97.34 VG)	82.08 ABab (94.67 VG)	71.20 BCab (87.34 S)	86.51 Aab (98 VG)	67.00 Ab (78.69 D)	81.34 Aab (94 G)	90.00 Aa (100 E)	70.53 Bab (85.33 S)
120 DAA	100.00	*I. hederifolia*	86.51 Aa (98 VG)	81.11 Aa (90 S)	83.02 Aa (96 S)	83.48 Aa (94 G)	90.00 Aa (100 E)	18.66 Ab (12 NO)	90.00 Aa (100 E)	73.39 Aa (82 D)	81.34 Aa (94 S)
	98.00	*I. quamoclit*	77.85 Aa (92 S)	90.00 Aa (100 E)	90.00 Aa (100 E)	74.82 Aba (88 S)	70.47 Aa (80 D)	26.90 Ab (22 VP)	63.59 Aab (74 I)	75.75 Aa (86 S)	70.59 Aba (82 D)
	100.00	*M. cissoides*	90.00 Aa (100 E)	72.23 Aab (80 D)	51.29 Bbc (54 P)	83.48 Aab (94 G)	90.00 Aa (100 E)	24.46 Ac (22 VP)	77.46 Aab (84 I)	90.00 Aa (100 E)	90.00 Aa (100 E)
	86.00	*P. maximum*	76.03 Aabc (92 S)	78.78 Aabc (90 S)	44.78 Bcd (48 P)	45.40 Bbcd (48 P)	82.27 Aab (92 S)	32.16 Ad (34 P)	81.34 Aabc (94 G)	81.11 Aabc (90 S)	90.00 Aa (100 E)
	84.00	*B. decumbens*	62.28 Aa (72 I)	74.82 Aa (88 S)	67.12 Aba (56 P)	52.11 Ba (56 P)	72.26 Aa (84 D)	45.95 Aa (46 P)	61.75 Aa (70 I)	77.10 Aa (88 S)	49.81 Ba (52 P)

Upper case: to be compared on columns and lower case, on rows; original data in brackets; transformed data in arc sen root x+0.5/100 accompany Tukey test letters at 5%; B= good; E= excellent; D= doubtful; S= sufficient and P=Poor; VG=very good; SE=no effect; very bad; T1-untreated; T2- imazapic (147 g ha^{-1}); T3-imazapic(98 g ha^{-1})+sulfentrazone(600 g ha^{-1}); T4- sulfentrazone(800 g ha^{-1}); T5-tebuthiuron(1000 g ha^{-1});T6-amicarbazone(1400 g ha^{-1}); T7-flumioxazin(125 g ha^{-1}); T8-diuron(1066 g ha^{-1})+hexazinone(134 g ha^{-1})+imazapic (98 g ha^{-1});T9-amicarbazone(840 g ha^{-1})+isoxaflutole(82,5 g ha^{-1});T10- imazapic(98 g ha^{-1})+isoxaflutole (85 g ha^{-1}).