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Control of broadleave and grass weeds in *Saccharum officinarum* with the use of pre-emergence herbicides

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In order to identify combinations of effective preemergent herbicides for weeds in sugarcane, an experiment was conducted at the Agricultural School of Concepción; Concepción, Paraguay. The experimental model was subdivided plots, with two factors: A_1 without herbicide for broadleaf weeds, A_2 diuron (dose 3 t ha^{-1}), A_3 atrazine (dose 4 kg ha^{-1}), A_4 sulfentrazone (dose 1.2 t ha^{-1}) and B_1 without herbicide for weeds, B_2 trifluralin (dose 3 l ha^{-1}), B_3 acetochlor (dose 1 l ha^{-1}), forming twelve treatments with three repetitions. They were applied in preemergence, where the evaluations were from 20 to 41 days after application (DDA), for: degree of control, residual effect and control of predominant weeds. The combination of diuron and acetochlor, produced high weed control (more 90% up to 41 days DDA), being superior to the other treatments. *Sida* spp was better controlled with diuron; whereas *Mollugo verticillata* was effectively controlled with most combinations; *Ipomoea nil* was more sensitive to sulfentrazone, while; *Cenchrus echinatus* was effectively controlled, with the combination of diuron plus acetochlor. It is concluded that with the combination of diuron and acetochlor, a large variety of weeds was controlled and the highest residual effect was recorded. In addition, atrazine combined with graminicides (trifluralin or acetochlor) or diuron with acetochlor, provided total control of weeds. It is recommended: for *Sida* spp. diuron with acetochlor or atrazine. For *Mollugo verticillata*, sulfentrazone alone or combined with graminicides. *Ipomoea nil*, sulfentrazone. *Cenchrus echinatus*, diuron and acetochlor combined.

Key words: *Saccharum officinarum*, weeds, preemergence herbicides.

INTRODUCTION

In Paraguay, according to CAN (2008), 95.3% of the farms have at least a small area dedicated to the cultivation of sugarcane; In the department of Concepción, this item is essential in rural farms. The initial development of the sugarcane plant is slow; therefore, if the weeds are not removed during this critical time; determined according to López (1988), in the first 35 to 90 days after implantation the population and crop

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production can be reduced by up to 40% (Toledo and Cruz, 2012).

Weeds compete with crops for water, light, and nutrients. Sugarcane is especially sensitive to competition with invasive plants, and according to Valle et al. (2000), if an efficient and timely control is not carried out, production may be affected, as well as behaving as host of pests.

The use of herbicides is replacing the mechanical and manual methods of weed control, since it offers advantages such as: its rapid application, safety for cultivation, effectiveness for control, solution to the lack of labor and prolonged residual power.

It is in this context that we propose to establish some strategies to give a solution to the problems of weeds, because consequently they can cause the reduction of sugarcane production. This measure is to present a technology, that is, an effective alternative for the control of invasive plants. This would involve the application of combined herbicides with other chemical bases, for the eradication of invasive plants.

In this research work, the objective was to identify the combinations of preemergence herbicides that are most effective for the control of *Sida* spp, considered by Díaz (2003), of the main weeds in sugarcane; *Mollugo verticillata*, Arias and Salazar (1999), mention it among the most abundant weeds in the cultivation of sugarcane. *Ipomoea nill*, counted among the worst weeds of sugarcane (Roncaglia and de Marco, 1995; Cordova et al., 2014); *Cenchrus echinatus*, cited among the most important weeds in sugarcane crops (Valle et al., 2000) weeds and broadleaf weeds in the cultivation of sugarcane.

MATERIALS AND METHODS

The experiment was conducted at the Agricultural School of Concepción, (23° 22' 44.77"S and 57° 23'26.64" W). The average temperatures vary between 23 and 17°C, with maximum of 41°C in the summer season and minimums of 5°C in the winter season, with slight incidences of frost. The annual average precipitation is around 1500 mm (DINAC, 2016). The soil of the region is characterized as clear thin sandy texture with weak structure. López et al. (1995). The experimental design used was subdivided plots (4 × 3), consisting by 12 treatments with 3 replicates, which were laid out in 4 main plots and divided into 3 sub plots for the application of treatments. Each experimental unit consisted of 3 rows (or rows) of 6 m in length and 1.20 m between each of them. This represented a surface area for the experimental units of 21.6 m^2. The total experimental area was 950 m^2. The treatments were, Control (A_1 + B_1), trifluralin (A_1 + B_2), acetochlor (A_1 + B_3), diuron (A_2 + B_1), diuron + trifluralin (A_2 + B_2), diuron + acetochlor (A_2 + B_3), atrazine (A_3 + B_1), atrazine + trifluralin (A_3 + B_2), atrazine + acetochlor (A_3 + B_3), sulfentrazone (A_4 + B_1), sulfentrazone + trifluralin (A_4 + B_2), sulfentrazone + acetochlor (A_4 + B_3). The choice of this experimental area was taking into account the infestation of weeds. The preparation of the site was carried out in a conventional way, by using a heavy harrow, followed by cleaning and levelling of the land to leave a smooth seedbed. For sowing, the canes were cut, leaving stakes with 3-4 buds, which were later deposited and distributed in the furrows to approximately 0.3 m depth. The herbicides were applied out immediately after planting and following precipitation, preemergence to the weeds using a backpack sprayer, of 20 L of capacity, which works at an approximate pressure of 5 Kg/cm²; being necessary approximately 10 charges for the coverage of 1 ha. The herbicides were applied individually, in order to avoid later problems such as those cited by Urrretabiscaya et al. (2016), which mention problems such as: incompatibility of mixtures with phase separation, clot formation, coalescence, flocculation, sedimentation; because of: low volume of water (higher concentration), hard water (affect the emulsifier), low temperature (lower solvent capacity of the water and slow chemical reaction speed), rapid spillage of the agrochemical (little time to dissolve), poor agitation (little return or misplaced), and finally an incorrect mixing order. The concentration of active ingredient and dose for each of the products applied was shown in Table 1. The evaluated parameters were:

Table 1. Concentration of active ingredient and dose of herbicides used.

Products	Concentration (%)	Dose	Unity
Trifluralin	50	3	$L.Ha^{-1}$
Acetochlor	84	1	$L.Ha^{-1}$
Diuron	50	3	$L.Ha^{-1}$
Atrazine	75	4	$Kg.Ha^{-1}$
Sulfentrazone	50	1.2	$L.Ha^{-1}$

Weed control: The evaluations were carried out at four intervals; at 20, 27, 34 and 41 days after treatment by quantifying emerged weeds compared to the control by means of a 0.25 m^2 quadrat. The percentage of controlled weeds was recorded according to the scale of Truelave (1977).

Residual effect: The period during which the herbicides had pre-emergence control of the weeds was evaluated by quantifying weeds that emerged in the matched control, as in the plots that received the applications. The evaluations were made at 20, 27 34 and 41 DDA.

Control of the predominant weeds: The most dominant weeds were evaluated by quantifying them compared to the control. Data were subjected to analysis of variance (ANOVA) using the Test F (5%) and significant effects were subjected to a comparison of means by Tukey (5%).

RESULTS AND DISCUSSION

Weed control

In the absence of herbicides for grassy weeds (B_1), the herbicides diuron and atrazine resulted in weed controls of 80 and 79% respectively, being superior to the control obtained with sulfentrazone (65%). Faced with a high population of broadleaf weeds in the experimental plot, the high degree of control obtained with selective broadleaf herbicides can be attributed to the efficacy of the product and its high residual power. Also, Esqueda, (1998) obtained 87% control of broadleaf weeds with the

Table 2. Comparison of averages for the determination of weed control (%) with the use of preemergence herbicides in *Saccharum officinarum*.

Weed control (%)			
Factor A	**Factor B**		
	Without Herbicide	**Trifluralin**	**Acetochlor**
Without Herbicide	$0^{cC(1)}$	24^{cB}	37^{cA}
Diuron	$80^{a\ B}$	82^{abB}	$92^{\ aA}$
Atrazina	79^{aB}	89^{aA}	$71^{\ bC}$
Sulfentrazone	65^{bB}	79^{bA}	72^{bAB}

([1]) Equal letters, lowercase in columns and uppercase in rows, indicate statistical equality through the Tukey test with 5% error probability. Factor A: herbicide for the control of broadleaf weeds; Factor B: herbicide for the control of fine leaf weeds.

application of atrazine in sugarcane.

In combination with the graminicide trifluralin (B_2), atrazine resulted in 89% weed control, being significantly superior to the control obtained with the herbicide sulfentrazone. The diuron showed a good control of 82%, but statistically similar to sulfentrazone with 79%. Combined with acetochlor (B_3), the herbicide diuron resulted in the highest percentage of weed control (92%), being significantly higher than those obtained with the other herbicides (atrazine and sulfentrazone). Alfaro et al. (2002), obtained adequate levels of control (more than 90%), with the combination of hexazinone, diuron and 2,4-D + picloran; results similar to those achieved in this investigation with the combination of diuron and acetochlor.

The use of selective herbicides for broadleaves, either alone or combined with graminicide herbicides, resulted in a high percentage of weed control, with all cases being significantly superior to the control without herbicide (Table 2). When the diuron treatment was used, the herbicide acetochlor was found to have the highest percentage of control (92%), being significantly higher than that obtained from the combination of diuron with the herbicide trifluralin, which did not present any additional control. According to Guevara (2014), some pre-emergent herbicides such as diuron, are used in combination with Acetochlor, to extend the spectrum of control.

In combination with atrazine (A_3), the herbicide trifluralin resulted in the highest percentage of weed control of 89%, being significantly higher than that obtained with acetochlor. The degree of weed control with atrazine decreased significantly with the application of acetochlor (71%); being these data superior to those reached by Alfaro et al. (2002), who obtained 54% control, with the mixture of atrazine, ametryn and 2,4-D + picloran).

In combination with sulfentrazone (A_4), trifluralin showed the highest percentage of weed control (79%), being significantly higher than the control percentage of acetochlor. Cantamutto et al. (1996), report that in works on early application of melon cultivation herbicides, trifluralin, made control of weeds, both broadleaved and grasses. With respect to the use of selective herbicides for fine leaf weeds, individually they do not demonstrate high percentages of control. In combination with herbicides for broadleaf weeds, in general, they seem to enhance the effects of these, with the exception of acetochlor with atrazine, which decreases the control exerted individually by atrazine. This may be due to the lower incidence of grasses in the total weed population, and in some cases due to the decrease in the phytotoxic effect of graminicides as a consequence of mixtures with some of the broadleaved herbicides.

Residual effects

Table 3 shows the residual effect (%) in the different treatments. In general, the graminicides showed low levels of weed control until 20 days after their application, reaching the highest values of control with acetochlor (66%). The percentage of weed control of the graminicide herbicides decreased to levels below 50% from 27 days after the application (DAA). These results indicate that the graminicides had a rather deficient effect until 20 days after its application. However, Villegas, (2011) in an experiment carried out to control weeds in chia cultivation, showed that trifluralin offers good control until 20 days after application. On the other hand, Alfaro et al. (2002), I observe a reduction of the residual power of acetochlor decreasing of 81.43% at 75 days after the application; up to 10.16% at 90 days after the application. With the use of diuron as a herbicide for broad leaves, without combination with other herbicides a good residual effect was obtained up to 34 DDA, reaching very good levels of weed control, higher than 80%; from which it progressively decreased its control effect until reaching 59%. González et al. (2018), with the use of diuron in sugary sorghum culture, I observed a 70% weed control, at 35 days after the application; maintaining these levels of control until 50 days after the application.The herbicide diuron substantially improved the percentage and the residual period of weed control when it was combined

Table 3. Comparison of averages for the determination Residual effect (%) of the herbicides used to control weed in *Saccharum officinarum* at 20, 27 34 and 41 days after application (DAA).

Treaments	Days after the application (DAA)			
	20	27	34	41
Control	0	0	0	0
Trifluralin	42 to ^{C}	33 ^{aD}	10 ^{bFG}	10 ^{bD}
Acetochlor	66 to ^{B}	46 ^{bD}	26 ^{cF}	9 ^{dD}
Diuron	85 ^{aA}	90 ^{aAB}	85 ^{aABC}	59 ^{bC}
Diuron + Trifluralin	93 ^{aA}	93 to ^{AB}	78 $^{b\ ABCD}$	65 ^{bC}
Diuron +Acetochlor	87 ^{aA}	97 $^{a\ A}$	92 ^{aA}	94 to ^{A}
Atrazine	91 ^{aA}	81 ^{abBC}	74 ^{bBCD}	70 ^{bBC}
Atrazine +Trifluralin	87 ^{aA}	94 ^{aAB}	90 ^{aAB}	83 ^{aAB}
Atrazine +Acetochlor	67 ^{aA}	70 ^{BC}	73 to ^{CD}	75 ^{aBC}
Sulfentrazone	61 ^{bcB}	83 ^{aABC}	50 ^{cE}	66 ^{bC}
Sulfentrazone + Trifluralin	91 ^{aA}	93 ^{aAB}	64 ^{bOF}	67 ^{bBC}
Sulfetrazone +Acetochlor	59 ^{bB}	80 ^{BC}	76 $^{a\ ABCD}$	73 ^{Bc}

Equal letters, lowercase in columns and uppercase in rows, indicate statistical equality through the Tukey test with 5% error probability.
Factor A: Herbicide for the control of broadleaf and fineleaf weeds; Factor B: Moments of evaluation.

with the graminicide herbicide acetochlor, reaching 94% control of the at 41 days after application. Diuron combined with trifluralin had a high weed control until 27 days after its application (93%), after which it gradually decreased its residual effect until reaching moderate levels of weed control at 41 DAA (65%). Similar results of the residual effect of the herbicide diuron was found by Esqueda (2005) who verified a level of weed control higher than 95% up to 30 DAA, which decreased slightly with time until 80% of weed control was reached. 90 days after its application. Metzler and Ahumada (2013) also observed that there was a moderate level of 80% weed control with the use of diuron.

With the use of atrazine without combination with graminicides, the highest percentages of weed control were obtained up to 27 DAA (higher than 80%), significantly decreasing its effect from 34 DAA until reaching moderate levels of weed control (around 70%). Gonzalez et al. (s.f.), could observe that the residual effect of atrazine remained at control levels of 50%, between 35 and 100 DAA. Atrazine significantly increased its residual effect when combined with trifluralin, reaching high weed control percentages (above 80%) until 41 days after its application. However, when atrazine is combined with acetochlor, its degree of weed control significantly decreased to moderate levels (around 70%) but constant until the end of its evaluation (41 DAA). According to Metzler and Ahumada (2013), in an investigation on the control of weeds with preemergence herbicides, using atrazine and making observations at 30 DAA up to 70 DAA, obtained control of 85% of weeds.

With the use of sulfentrazone moderate control of the weeds was obtained (around 80%) up to 27 DAA; in this sense Diez (2013), mentions that the residual effect of sulfentrazone, is variable in some cases has no residual effects on the soil to be absorbed into organic matter and soil clays, in addition to being sensitive to microbial decomposition, while in other cases it can remain active for 3 to 8 weeks. Control by sulfentrazone was significantly increased to levels above 90% when in combination with trifluralin but did not increase its residual effect at 27 DAA. Sulfentrazone combined with acetochlor showed a moderate degree of weed control (greater than 70%) during the entire evaluation period of the experiment (41 DAA).

Control of predominant weeds

Table 4 shows the control of predominant weeds (%) in the different treatments.

Control of *Sida* spp

All the herbicides for grass weeds applied resulted a very low percentage of mallow control. However, in mixtures of diuron with acetochlor and the use of atrazine alone or in a mixture with acetochlor resulted in the highest percentages of control of the mallow, reaching levels of 100% and close to 100%, respectively. The diuron only showed moderate control of the mallow (75%). However, when this herbicide was mixed with graminicides, the control percentage of the mallow increased to very good levels, reaching 88% when it was mixed with trifluralin

Table 4. Comparison of averages for the determination of control for predominant weeds (%) with preemergence herbicides in *Saccharum officinarum.*

Treaments	*Sida* spp	*Mollugo verticillata*	*Ipomea nil*	*Cenchrus echinatus*
Witness	0	0	0	0
Trifluralin	28^{aD}	88^{aB}	43^{aD}	83^{aB}
Acetochlor	13^{bD}	48^{bD}	28^{bD}	43^{bD}
Diuron	75^{cC}	97^{bB}	25^{cD}	84^{cB}
Diuron+Trifluralin	88^{bB}	92^{cB}	75^{aC}	88^{bB}
Diuron+Acetochlor	100^{aA}	100^{aA}	50^{bC}	94^{aB}
Atrazine	99^{aA}	88^{bB}	69^{bC}	56^{aC}
Atrazine+Trifluralin	75^{bC}	100^{aA}	74^{aC}	40^{bD}
Atrazine+Acetochlor	98^{aA}	100^{aA}	69^{bC}	40^{bD}
Sulfentrazone	78^{aC}	100^{aA}	92^{aB}	40^{bD}
Sulfentrazone+Trifluralin	29^{cD}	100^{aA}	38^{cD}	65^{aC}
Sulfentrazone+Acetochlor	70b^{C}	100^{aA}	76b^{C}	30^{cD}

Equal letters, lowercase in columns and uppercase in rows, indicate statistical equality through the Tukey test with 5% error probability. A: Full effect (Excellent weed control); B: Severe effect (Very good weed control); C: Moderate effect (Moderate weed control); D: Light effect (Poor weed control); E: No effect (Very poor weed control).

and 100% of control when combined with acetochlor. This of diuron with acetochlor resulted in control percentage significantly higher than those obtained with diuron alone or mixed with trifluralin. Lorenzi (2014) found that *Sida* spp is highly susceptible to diuron with more than 95% control; although these results do not correspond to what was obtained in the current investigation since the herbicide had inferior results.

The use of atrazine alone or in a mixture with acetochlor showed high percentages of control of *Sida* spp (99 and 98%, respectively). However, the control by atrazine was negatively affected when this herbicide was mixed with trifluralin as control decreased to 75%. Atrazine, according to Lorenzi (2014), shows good control of more than 90%, which confirms the results of this research work. Sulfentrazone only showed a moderate degree of control of *Sida* spp (78%), but this lost its effect when it was mixed with both graminicides, namely acetochlor and trifluralin.

Control of *Mollugo verticillata*

Trifluralin, showed good control of *M. verticillata* (82%), being significantly greater than the control by acetochlor. Sulfentrazone, individually or combined with Trifluralin and Acetochlor; the Diuron combined with Acetochlor; and Atrazine combined with Trifluralin and Acetochlor, showed 100% control of this weed. Diuron, either alone or in a mixture with the graminicides, showed control of *M. verticillata* greater than 90%. Diuron in a mixtures with acetochlor obtained the highest percentage of control of *M. verticillata* (100%), being significantly greater than that obtained with diuron alone (97%) or the mixture of diuron with trifluralin (92%). Esqueda (1999), investigating with different mixtures of herbicides in pre and post emergency, in the sugarcane crop, could observe total control of *M. verticillata*, up to 90 DDA, with the combined use of diuron + hexazinone and ametryn + atrazine, applied in preemergence. Atrazine had a high control percentage of 88% of *M. verticillata*, whose effect was significantly increased with the combination with the herbicides trifluralin and acetochlor, reaching 100% control.

Control of *Ipomoea nil*

Sulfentrazone resulted the highest percentage of control of *Ipomoea nil* (92%), being significantly higher than those obtained by the single applications of diuron and atrazine, whose control percentages was 25 and 69% respectively. These results are in agreement with the work carried out by Fernández et al. (2011) for the control of the weed *Ipomoea purpurea* with preemergence use of sulfentrazone, where controls of 90% was obtained in a soybean crop. Likewise, Canaza and Fernandez (2016), using sulfentrazone in combination with other herbicides in the soybean crop, observed 94.34% control for this weed at 10 DAA, decreasing this figure to 44% at 20 DAA; and being ineffective after 38 DAA.

The use of diuron and atrazine, combined with trifluralin, resulted in good percentages of control of *Ipomoea nil*, reaching 75 and 74%, respectively. This was significantly greater than results from these herbicides combination with acetochlor. The combination between

sulfentrazone and acetochlor, resulted in control of *Ipomoea nil* at 76%, which was significantly greater than the combination with trifluralin.

Control of *Cenchrus echinatus*

Trifluralin resulted in the highest percentage of control of *C. echinatus*, at 83% being superior to the control obtained by acetochlor (43%) *C. echinatus* is highly susceptible at 100% control to the action of the herbicide trifluralin when applied preemergence (Lorenzi, 2014). With the use of diuron, either alone or in mixtures, the highest percentage of control of poaceae was obtained, being significantly higher than that obtained by atrazine and sulfentrazone at 56 and 40%, respectively. When the diuron was combined with acetochlor, the highest percentage of control of *C. echinatus* was obtained (94%), being significantly superior to the control obtained by diuron plus trifluralin at 88%. Atrazine alone or in combination with other graminicides herbicides showed a very low percentage of *C. echinatus* control of 56%. In combination with the graminicides, the control by atrazine of *C. echinatus* decreased, most probably due to problems of incompatibility of the herbicides mistures. Sulfentrazone application resulted in very low control of *C. echinatus* (40%). However, there was a significant increase in control when this herbicide was combined with trifluralin, reaching 65%. However, when the sulfentrazone is combined with acetochlor the percentage of control was reduced considerably to 30%, which indicates the occurrence of an antagonism between the herbicides.

Conclusions

With the use of preemergence herbicides, diuron with acetochlor, effectiveness was achieved for the control and reduction of a great variety of weeds. In addition, the same combination offers the best residual effect with 94% control until 41 days after application.

RECOMMENDATIONS

To obtain control of *Sida* spp. diuron with acetochlor or atrazine may be used. For the control of *M. verticillata*, sulfentrazone alone or combination with grass herbicides such as trifluralin or acetochlor are effective. In addition atrazine and its mixture with graminicides (trifluralin or acetoclor) or diurón with acetoclor, offers total control of the weed. In order to obtain control of *Ipomoea nil*, the use of sulfentrazone may achieve very good efficacy and thus reduce the impact that the weed might cause. Control of *C. echinatus*, will be obtained with the combination of diuron and acetochlor with which satisfactory effects will be achieved.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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