Colegio de Postgraduados

Evaluation of pre-plant herbicides for maize (*Zea mays* L.) cultivation

Valdez-Hernández, Miguel A.[1*]; Cisneros-López, Ma. Eugenia[1]; Hernández-Martínez, Rosendo[1]; Espinosa-Ramírez, Martín[1]; Ruiz-Ramírez, Santiago[2*]; Arispe-Vázquez, José L.[3]

[1] Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias. Campo Experimental Río Bravo, carretera Matamoros-Reynosa km 61, Río Bravo, Tamaulipas, México. C. P. 88900.

[2] Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias. Campo Experimental Centro-Altos de Jalisco. Av. Biodiversidad No 2470. Tepatitlán de Morelos, Jalisco, México. CP 47600.

[3] Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias. Campo Experimental Iguala, carretera Igual-Tuxpan, km 2.5, Igual Guerrero, México. C.P. 40000.

* Correspondence: valdez.miguel@inifap.gob.mx; ruiz.santiago@inifap.gob.mx

ABSTRACT

Objective: To evaluate the efficacy of different herbicides for weed control, prior to the establishment of maize crops (*Zea mays* L.).

Design/methodology/approach: An experiment was established during the SS/2022 and FW/2023 cultivation cycles. The design was completely random blocks and four repetitions with the following treatments: control, glyphosate 726 g ha^{-1}; paraquat 400 g ha^{-1}; glufosinate-ammonium 300 g ha^{-1}; saflufenacil 42 g ha^{-1}; 2,4-D amine 718.5 g ha^{-1}; dicamba + 2,4-D 120 + 240 g ha^{-1}; picloram + 2,4-D 64 + 240 g ha^{-1}; glufosinate-ammonium + 2,4-D 300 + 479 g ha^{-1}; glyphosate + 2,4-D 726 + 479 g ha^{-1} and BH 03 (bioherbicide) concentration at 1%. The damage to weeds was evaluated 7, 14 and 21 days after application (DAA).

Results: The most efficient control of polote (*S. eurylepis*) was with glyphosate, paraquat, glufosinate-ammonium, saflufenacil, dicamba + 2,4-D, glufosinate-ammonium + 2,4-D, and glyphosate + 2,4-D, all of them with control levels equal or higher than 90%. In zacate panizo (*U. reptans*), the most efficient were glyphosate and paraquat, with values higher than 97%.

Limitations on study/implications: The results correspond to *S. eurylepis* and *U. reptans* as most frequent weeds. Conditions of excessive rain or wind delay the optimal application time. After sowing, early weeds can escape control.

Findings/conclusions: Glyphosate and paraquat were the most efficient herbicides during the evaluation in both agricultural cycles.

Keywords: *Simsia eurylepis*, *Urochloa reptans*, Control.

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INTRODUCTION

Maize (*Zea mays* L.) (Poaceae) growing is one of the most important in the state of Tamaulipas. During the 2023 cycle, 114,808.6 ha were cultivated, with a value of $2,618 million pesos. In the municipality of Abasolo, 14,162 ha were established, with an average yield of 5.83 t ha and a value of $489 million pesos (SIAP, 2025). However, production of this grain faces numerous challenges, which include biotic factors such as weeds, nematodes, pathogens

and pests; and abiotic factors such as soil problems, unfavorable climate, nutritional deficits, and agronomic, logistical and social limitations (Batool *et al.*, 2025).

Weeds are one of the most important factors that affect the development of a crop, since they compete directly with the established crop (Alptekin *et al.*, 2023). Reports have estimated that weeds cause a loss of around 37% of global production (Sharma and Rayamajhi, 2022).

Weed control in the pre-planting stage of the maize crop is fundamental, since it allows eliminating the unwanted plant species previously established in the terrain, reducing the competition over resources during the initial phases of crop development (Silva *et al.*, 2023). Among the most used herbicides in the world during this stage, there is glyphosate, a compound of non-selective action that has proven to be highly effective in the control of a wide range of weeds before planting, thus favoring a more uniform and efficient establishment of the crop (Koning *et al.*, 2016). The main characteristics of this chemical are its low cost, efficiency in the control, and quick absorption (Rivas-Garcia *et al.*, 2022). Currently, there are more herbicides in the market that can be used before planting, such as paraquat, glufosinate-ammonium, saflufenacil, 2,4-D, dicamba + 2,4-D, and picloram + 2,4-D. Likewise, in recent years, the use of organic or botanical bioherbicides derived from allelopathic plants is suggested, as a sustainable control method (Hasan *et al.*, 2021). Paraquat is a contact herbicide, due to its limited mobility in the plants; it belongs to the family of bipyridyls and acts as an electron acceptor of the photosystem I (PSI) inside the chloroplasts, which inhibits the photosynthesis process and causes the quick death of plant cells (Miller *et al.*, 2024). Glufosinate-ammonium is a non-selective herbicide, of post-emergence application and broad spectrum; it is effective for weed control, since it acts by blocking glutamine synthetase, an essential enzyme for nitrogen assimilation, metabolism, and photo respiration (Duenk *et al.*, 2023). Saflufenacil is an herbicide that acts as inhibitor of protoporphyrinogen oxidase (PPO), interrupts chlorophyll biosynthesis, and is efficient at low concentrations of the active ingredient (Yin *et al.*, 2023). 2,4-D, dicamba and picloram belong to the family or growth or auxin regulators; they are synthetic compounds that imitate natural auxins, promoting an abnormal growth in plant cells (Goggin *et al.*, 2023). Because of this, the objective of this study was to evaluate the efficacy of different herbicides for pre-plant weed control in maize cultivation. The proposal of the research hypothesis is that at least one herbicide can match or outperform glyphosate.

MATERIALS AND METHODS

Study area

The study was established in the Experimental Site "Las Adjuntas" of the National Forestry, Agriculture and Livestock Research Institute (*Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias*, INIFAP), with coordinates 24° 05' 21.3" N, −98° 23' 50.9" W, in the municipality of Abasolo, Tamaulipas. The experimental lots presented loam-clay-sand texture (56.76% sand, 16% loam, and 27.24% clay), pH 7.9, and 1.79% organic material. These soils were selected because they had high populations of weeds that are common in the municipality.

Terrain preparation

In the first experiment, the soil preparation consisted of a single plow, followed by raking twice, and plowing through the terrain. In the second experiment, the same preparation was carried out, except for the last plowing, which was omitted.

Identification and quantification of weeds

Before application of the treatments, the density of weeds was determined, through a 0.5 m^{-2} quadrant, which was extrapolated to m^{-2}. The quadrant was placed randomly within the plots; the species were counted, and the height (cm) of the weeds was measured. The identification was carried out through their morphological characteristics (Sánchez Ken *et al.*, 2012; Ronda-Martínez, 2022).

Experimental design

The experimental design was complete random blocks, with 11 treatments and four repetitions. The experimental unit was 3 m wide by 10 m long.

Application of treatments

The treatments evaluated were: control, glyphosate (726 g a.i. ha^{-1}); paraquat (400 g a.i. ha^{-1}); glufosinate-ammonium (300 g ia ha^{-1}); saflufenacil (42 g a.i. ha^{-1}); 2,4-D amine (718.5 g a.i. ha^{-1}) (later known as 2,4-D); dicamba + 2,4-D (120 + 240 g a.i. ha^{-1}); picloram + 2,4-D (64 + 240 g a.i. ha^{-1}); glufosinate-ammonium + 2,4-D (300 + 479 g a.i. ha^{-1}); glifosate + 2,4-D (726 + 479 g a.i. ha^{-1}), and the commercial bioherbicide BH 03 (enzymatic organic acids 10%, extract of allelopathic wild plants 38%, *Puccinia* spp. toxins 2%, non-ionic pine resin (surfactant) 20%, and diluent 30%) at concentration of 1% (2.5 mL L^{-1}).

The treatments were applied on June 1, 2022, and September 29, 2023, prior to the establishment of the maize crop. The application of herbicides was carried out with a motorized backpack sprayer (Mod. KP, Forza 25; Swissmex, Mexico), equipped with an 8002 six-nozzle flat fan boom, placed at distance of 0.5 m between each. Exit pressure of 275 kPa was used, and spraying volume of 250 L ha^{-1}. Water from the irrigation channel was used, with pH of 7.7, to which a pH regulator and non-ionic emulsifier were added, both at a dose of 1 ml L^{-1} for all the treatments.

Evaluation of weed control

For the evaluation of toxicity of herbicides on the weed, the scale proposed by the European Weed Research Society (EWRS) was used, in terms of percentage, where: 1: 99-100% control; 2=96.5-99.0, very good control; 3=93.0-96.5, good control; 4=87.5-93.0, enough control; 5=80.0-87.5, medium control; 6=50.0-80.0, regular control; 7=50.0-70.0, poor control; 8=1.0-50.0, very poor control; and 9=0.0-1.0, without effect (Champion, 2000). The evaluation was carried out by means of visual estimations of 0.0 to 100.0%; where 0.0% indicates no effect and 100.0% death of the plant 7, 14 and 21 days after application (DAA).

Data analysis

The data on percentage of weed control were transformed through the square root arcsine function of X/100 before their analysis, with the aim of homogenizing their variances (Dey and Pandit, 2020). Then, the results of the treatments were subjected to analysis of variance (ANOVA), in a combined analysis for the treatments with herbicides (T=11) and years (A=2022 and 2023). The measurements were carried out with the Least Significant Differences (LSD) test (LSD) ($p \leq 0.05$). In the case of broadleaf weeds, results of the 11 treatments were reported (control, glyphosate, paraquat, glufosinate-ammonium, saflufenacil, 2,4-D, dicamba + 2,4-D, picloram + 2,4-D, glufosinate-ammonium + 2,4-D, glyphosate + 2,4-D, and commercial herbicide BH 03); for narrow leaves, only the results for seven treatments are reported (control, glyphosate, paraquat, glufosinate-ammonium, glufosinate-ammonium + 2,4-D, glyphfosate + 2,4-D, and BH 03), because the herbicides dicamba, picloram, 2,4-D (alone), and saflufenacil are not recommended.

The combined analysis of the data indicated interaction between the treatments by years, so the variables are presented separately for each year. The results are presented with original field data, but with the letters of means comparison corresponding to the analysis performed with transformed data. Data analysis was conducted using SAS 9.4 software (SAS Institute, 2016).

RESULTS AND DISCUSSION

Identification of weeds

Two species of weeds were identified in the experimental unit: polote (*Simsia eurylepis* S.F. Blake) and zacate panizo [*Urochloa reptans* (L.) Stapf].

In the north-center region of Tamaulipas, there are several species of weeds, which are considered of agronomic importance in pre-planting for the maize crop, such as zacate panizo [*U. reptans* (L.) Stapf] (Poaceae), which is a species of broad distribution also in the states of Veracruz, San Luis Potosí, Jalisco, Campeche, Chiapas, among others (Sánchez, 2011). There is also the broadleaf weed, *S. eurylepis* S.F. Blake, whose common name is “polote”; it is a species of the Asteraceae (Compositae) family, which grows in the states of Veracruz, Campeche, Nuevo León and San Luis Potosí (CONABIO, 2025).

In the 2022 spring-summer cycle, polote presented an average height of 7 cm and a density of 11 plants m^{-2}. In the 2023 fall-winter cycle, it reached an average height of 5 cm and density of 26 plants m^{-2}. In 2022, zacate panizo reached an average height of 10 cm and density of 104 plants m^{-2}; meanwhile, in 2023 it presented an average height of 12 cm and density of 218 plants m^{-2}.

Weed control

The combined analysis of variance showed effect of the treatments, year and interaction in weed control during the evaluation period (data not presented).

Year 2022

Control of polote (*S. eurylepsis*)

There was very good control (97%) of polote with glyphosate at 14 DAA, with a decrease of 8% at 21 DAA (Table 1). The paraquat treatment showed total control of the weed at 14 DAA, with a slight reduction at 21 DAA. In turn, Carnero-Avilés *et al.* (2023) evaluated the active ingredients glyphosate and paraquat at doses of 726 and 300 g of i.a. ha^{-1}, respectively, for control of *S. eurylepis*, and they reported controls of 89% and 95%, which are similar results to those obtained in this study.

Glufosinate-ammonium presented control levels between 95% and 97.5% during the three evaluation periods (Table 1), reaching their maximum control at 14 DAA. This herbicide, of broad-spectrum action, is effective for the control of broad and narrow leaf weeds (Takano and Dayan, 2020).

Saflufenacil reached sufficient control (90.7%) until 21 DAA (Table 1). This herbicide is highly efficient in the control of broadleaf weeds, and its mode of action is peroxidative, which causes fast necrosis in susceptible plant tissues (Montgomery *et al.*, 2015).

Hormonal herbicides (2,4-D, dicamba + 2,4-D and picloram + 2,4-D) reached their maximum control level until 21 DAA, with control efficiencies of 94.7, 95.3 and 96.8%, respectively (Table 1). Similarly, Hernández-Ramírez *et al.* (2009) evaluated the mixture of dicamba + 2,4-D at a dose of 120 + 240 g a.i. ha^{-1} on *Simsia amplexicaulis* (Cav.) Pers., and reported 97% control at 30 DAA, result comparable to those obtained in this study. The mixture of glufosinate-ammonium + 2,4-D showed good control (96.5%) at 7 DAA, with slight decreases at 14 and 21 DAA (Table 1).

Table 1. Effect of control of treatments on polote *S. eurylepis* at 7, 14 and 21 DAA (% of control) Abasolo, Tamaulipas.

Treatment	Dose (g a.i. ha^{-1})	DAA		
		7	14	21
Control	0	0 e	0 f	0 c
Glyphosate	726	83.5 ab	97 abc	89 a
Paraquat	400	90 ab	100 a	98.7 a
Glufosinate-Ammonium	300	95.5 ab	97.5 ab	95 a
Saflufenacil	42	87.5 abc	77.5 bcde	90.7 a
2,4-D	718.5	32.5 d	62.5 e	94.5 a
Dicamba + 2,4-D	120+240	40 d	75 de	95.3 a
Picloram + 2,4-D	64+240	40 d	83.7 cde	96.8 a
Glufosinate-Ammonium + 2,4-D	300+479	96.5 a	95 abc	96.3 a
Glyphosate + 2,4-D	726+479	74 bc	88.7 abcd	98.5 a
BH 03	1%	67.5 c	62.5 e	47.5 b
CV		19.1	17.9	11.3

DAA: Days after application; BH 03: bioherbicide; CV: Coefficient of variation; g a.i. ha^{-1}: grams of active ingredient per hectare; Means followed by the same letter within each column are not significantly different (DMS, $p \leq 0.05$).

The mixture of glyphosate + 2,4-D obtained very good control (98.5%) up to 21 DAA (Table 1). In contrast, BH 03 showed poor control (67.5%) at 7 DAA, decreasing by 14 and 21 DAA; this treatment was only better than the control without application.

Control of zacate panizo (*Urochloa reptans*)

Good control (95%) of zacate panizo was observed with glyphosate at 14 DAA, although with a decrease in control at 21 DAA (Table 2). Meyer *et al.* (2021) evaluated glyphosate at a dose of 867 g a.i. ha^{-1} for the control of *Urochloa platyphylla* (Griseb), reporting a control of 99% at 28 DAA, results that are consistent with those obtained in this study. On the other hand, paraquat showed a similar behavior to that of glyphosate, reaching very good control at 14 DAA (97.5%), which is statistically different from the other treatments. In turn, Carnero-Avilés *et al.* (2023) evaluated the active ingredients glyphosate and paraquat at doses of 726 and 300 g a.i. ha^{-1}, respectively, for the control of *U. reptans* and reporting control levels of 94% for both herbicides.

Glufosinate-ammonium showed sufficient control at 7 DAA (90%), decreasing its effectiveness to 65% at 21 DAA (Table 2). Meyer *et al.* (2021) evaluated glufosinate-ammonium at a dose of 451 g a.i. ha^{-1} for the control of *U. platyphylla*, reporting a control of 86% at 28 DAA. The differences between these studies could be attributed to the height of the weed at the time of application, which was 7 cm in this study, in contrast with 21 cm reported by Meyer *et al.*, which influences significantly the herbicide's efficacy.

Treatments with saflufenacil, 2,4-D, dicamba + 2,4-D and picloram + 2,4-D were omitted in this evaluation, because they are specific herbicides for control of broadleaf weeds. In particular, the herbicide saflufenacil presented a limited efficacy on narrow leaf species, due to their mode of action and their particular characteristics of absorption (Grossmann *et al.*, 2010). Likewise, Milthila *et al.* (2011) pointed out that auxin herbicides have low or null control on narrow leaf weeds, given that these present different physiological responses and signaling pathways of auxins that confer better tolerance to this type of compounds.

Table 2. Effect of the control of treatments on zacate panizo *U. reptans* at 7, 14 and 21 DAA (% of control) Abasolo, Tamaulipas.

Treatment	Dose (g a.i. ha^{-1})	DAA		
		7	14	21
Control	0	0 e	0 f	0 f
Glyphosate	726	89.5 b	95 ab	93.5 a
Paraquat	400	93.7 a	97.5 a	94 a
Glufosinate-Ammonium	300	90 a	81.3 c	65 c
Glufosinate-Ammonium + 2,4-D	300 + 479	86.3 a	80 c	71.3 c
Glyphosate + 2,4-D	726 + 479	87.5 a	85 bc	85 b
BH 03	1%	55 b	57.5 d	50 d
CV		11.4	18.8	12.2

DAA: Days after application; BH 03: bioherbicide; CV: Coefficient of variation; g a.i. ha^{-1}: grams of active ingredient per hectare; Means followed by the same letter within each column are not significantly different (DMS, $p \leq 0.05$).

The mixtures of glufosinate-ammonium + 2,4-D and glyphosate + 2,4-D showed sufficient control (86.3 and 87.5%) at 7 DAA (Table 2), decreasing their effectiveness in later weeks. Previous studies have shown that the mixture in tank of glyphosate with auxin herbicides such as 2,4-D can improve weed control (Osipe *et al.*, 2017), which contrasts with the results obtained in this study.

The bioherbicide BH 03 presented very poor control (50-57.5%) (Table 2) during the three evaluation periods, surpassing only the control without application.

Year 2023

Control of polote (*S. eurylepsis*)

Glyphosate presented sufficient control (90%) of the polote weed up until 21 DAA (Table 3). Paraquat showed sufficient control (85 and 92.5%) at 7 and 14 DAA (Table 3). Glufosinate-ammonium obtained good control (94.5%) of the weed until 21 DAA (Table 3). Saflufenacil presented control between 95.2 and 98% (Table 3) during the whole evaluation period, reaching its maximum effectiveness of 98% at 14 DAA; 2,4-D and BH 03 obtained levels lower than 66%, surpassing only the control without application.

In turn, Carnero-Avilés *et al.* (2023) evaluated the active ingredients saflufenacil and 2,4-D at doses of 42 and 718.58 g a.i. ha^{-1}, respectively, for the control of *S. eurylepis*, reporting a control effect of 96 and 65%, which are similar results to those in this study.

The mixtures dicamba + 2,4-D and picloram + 2,4-D showed sufficient control (90 and 88.7%) until 21 DAA (Table 3). One of the main advantages of the use of auxin herbicides such as 2,4-D is their low cost and good efficiency in control of broadleaf weeds in agricultural fields (Mithila *et al.*, 2011).

Table 3. Effect of the control of treatments on polote *S. eurylepis* at 7, 14 and 21 DAA (% of control) Abasolo, Tamaulipas.

Treatments	Dose (g a.i. ha^{-1})	DAA		
		7	14	21
Control	0	0 g	0 f	0 f
Glyphosate	726	45 d	80 c	90 cd
Paraquat	400	85 b	80 c	92.5 bcd
Glufosinate-Ammonium	300	70 c	90 b	94.5 bc
Saflufenacil	42	95.2 a	98 a	96 ab
2,4-D	718.5	27.5 f	45 e	65 e
Dicamba + 2,4-D	120 + 240	32.5 ef	65 d	90 cd
Picloram + 2,4-D	64 + 240	40 de	68.7 d	88.7 d
Glufosinate-Ammonium + 2,4-D	300 + 479	90 b	97.2 a	99 a
Glyphosate + 2,4-D	726 + 479	62.5 c	91.2 b	96.5 ab
BH 03	1%	40 de	61.2 d	58.7 e
CV		7.8	5.6	5.7

DAA: Days after application; BH 03: bioherbicide; CV: Coefficient of variation; g a.i. ha^{-1}: grams of active ingredient per hectare. Means followed by the same letter within each column are not significantly different (DMS, $p \leq 0.05$).

On the other hand, the mixtures of glufosinate-ammonium and + 2,4-D and glyphosate + 2,4-D showed very good control (99 and 96.5%) at 21 DAA (Table 3), exceeding 90% of efficacy since 14 DAA. These results emphasize the potential synergy between herbicides of different modes of action for the effective management of broadleaf weeds.

Control of zacate panizo (*U. reptans*)

The treatments paraquat, glufosinate-ammonium, saflufenacil, glufosinate-ammonium + 2,4-D and glyphosate + 2,4-D showed very good control (98%) of zacate panizo starting at 14 DAA (Table 4), reaching 99% at 21 DAA. In turn, Lopes *et al.* (2024) evaluated the active ingredient glyphosate at a dose of 1,440 g a.i. ha^{-1} on the weed *Urochloa decumbens* (Stapf.) R.D. Webster and reported control of 95% at 21 DAA, results that agree with those obtained in this study.

On the other hand, the treatment BH 03 showed average control (86.5%) until 21 DAA (Table 4). This result differs completely from what was observed in Table 3, where a control of 57.5 % was found. Kumar *et al.* (2023) mentioned that the climate has an impact on the efficiency of herbicides, by influencing the growth and development of weeds, since the variations of temperature, moisture and CO_2 levels alter its physiology.

Table 4. Effect of the control of treatments on polote *S. eurylepis* at 7, 14 and 21 DAA (% of control) Abasolo, Tamaulipas.

Treatments	Dose (g a.i. ha^{-1})	DAA		
		7	14	21
Control	0	0 h	0 e	0 e
Glyphosate	726	82.5 bc	98 a	99 a
Paraquat	400	91.2 a	98 a	99 a
Glufosinate-Ammonium	300	72.5 d	98 a	99 a
Glufosinate-Ammonium + 2,4-D	300 + 479	77.5 cd	98 a	99 a
Glyphosate + 2,4-D	726 + 479	87.5 ab	98 a	99 a
BH 03	1%	42.5 e	88.7 b	86.5 b
CV		6.8	5.3	2.1

DAA: Days after application; BH 03: bioherbicide; CV: Coefficient of variation; g a.i. ha^{-1}: grams of active ingredient per hectare; Means followed by the same letter within each column are not significantly different (DMS, $p \leq 0.05$).

CONCLUSIONS

For the control of polote (*Simsia eurylepis*), the herbicides that presented the greatest control effect were glyphosate, paraquat, glufosinate-ammonium, saflufenacil, dicamba + 2,4-D, glufosinate-ammonium + 2,4-D, and glyphosate + 2,4-D, all of them with equal or superior control levels than 90% in both evaluation dates.

For the control of zacate panizo (*Urochloa reptans*), the best herbicides are glyphosate and paraquat, by reaching controls higher than 97% in both evaluation dates.

Together, glyphosate and paraquat stood out as the most efficient herbicides for the simultaneous management of both weed species in the study, consistently showing high levels of control in all the evaluation dates.

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