Comparison of natural and chemical herbicides for weed management in Veracruz, Mexico †

[Comparación de productos naturales y herbicidas sintéticos para el manejo de malezas en Veracruz, México]

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SUMMARY

Background. Synthetic herbicides have reduced crop yield losses due to competition with weeds. However, their excessive use has led to the development of resistant ecotypes and damage to health and the environment. In response, countries such as Mexico have issued decrees to reduce their use, prompting the search for alternatives to glyphosate. **Objective**. To determine the efficacy of five natural and three synthetic herbicides for arvenses control in Veracruz, Mexico. **Methodology**. At INIFAP's Cotaxtla Experimental site, Zecatryn, Sec Natural, Herbitech, Kill-Herbs, and Vinecide were evaluated, as well as glyphosate, paraquat, and ammonium glufosinate, using commercial doses. A randomized block design with four replicates was used. **Results**. Weed control was achieved between 80 and 90% with glyphosate and Sec Natural up to 40 days after application (DAA), with similar results to those of Herbitech, Kill-Herbs, and ammonium glufosinate (70-80%). Paraquat achieved 50%, while Zecatryn recorded less than 15%. **Implications**. Some of the natural herbicides evaluated could be used as alternatives to glyphosate. **Conclusions**. Glyphosate showed higher effectiveness, with control greater than 80% at 70 DAA. Sec Natural, Herbitech, and Kill-Herbs had good to moderate efficiency up to 40 DAA, positioning them as viable bioherbicide options in an integrated weed control approach.

Key words: *Baltimora recta*; *Ixophorus unisetus*; *Parthenium hysterophorus*; *Cyperus rotundus*.

RESUMEN

Antecedentes. Los herbicidas sintéticos han reducido la pérdida de rendimiento de los cultivos por competencia con malezas. Sin embargo, su uso excesivo ha generado ecotipos resistentes y daños a la salud y el ambiente. Ante esto, países como México han emitido decretos para reducir su uso, motivando la búsqueda de alternativas al glifosato. **Objetivo.** Determinar la eficacia de cinco herbicidas naturales y tres sintéticos para el control de arvenses en Veracruz, México. **Metodología.** En el Campo Experimental Cotaxtla del INIFAP, se evaluaron Zecatryn, Sec Natural, Herbitech, Kill-Herbs y Vinecide, junto con glifosato, paraquat y glufosinato de amonio, empleando dosis comerciales. Se utilizó un diseño de Bloques al Azar, con cuatro repeticiones. **Resultados.** El control de malezas alcanzó entre 80 y 90% con glifosato y Sec Natural hasta 40 días después de la aplicación (DDA), con resultados similares a Herbitech, Kill-Herbs y glufosinato de amonio (70-80%). Paraquat logró un 50%, mientras que Zecatryn registró menos del 15%. **Implicaciones.** Algunos de los herbicidas evaluados podrían utilizarse como alternativas al glifosato. **Conclusiones.** Glifosato mostró mayor efectividad, con control superior al 80% a los 70 DDA. Sec Natural, Herbitech y Kill-Herbs tuvieron eficiencia de buena a regular hasta los 40 DDA, posicionándolos como opciones viables de bioherbicidas en un enfoque de control integrado de malezas.

Palabras clave: *Baltimora recta*; *Ixophorus unisetus*; *Parthenium hysterophorus*; *Cyperus rotundus*.

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INTRODUCTION

Competition between crops and weeds is one of the main factors that decreases yield and producers' income in most production systems (Horvath *et al*., 2023). Globally, it is estimated that weeds can cause yield losses ranging from 30 to 50% (Quintero-Pertúz and Carbonó-De la Hoz, 2016), and in some cases, the loss can be total (Colbach *et al*., 2020). For example, in the 17 major crops of India, Gharde and Singh (2018) reported actual yield losses ranging from 13.8 to 35.8%, although potential losses range from 30.3% in wheat to 67.8% in sugarcane. In Mexico, it has been determined that when chemical treatments do not provide adequate control or when weeds are not adequately managed, crop yields can be severely affected. In the case of beans, yield reductions can range from 44 to 96% (Esqueda-Esquivel *et al*., 2025). For rice, losses can reach values between 61% and 100% (Esqueda-Esquivel *et al*., 2015), in corn from 63% to 92% (Fonteyne *et al*., 2022), and in wheat from 17% to 47% (Medina-Cázares *et al*., 2024).

For weed control, various methods are available, including manual, mechanical, biological, physical, and chemical approaches. Among these, herbicide application is the most commonly used method in the country for basic crops and fruit plantations, especially citrus. Herbicides can be applied to the soil (preemergence) or to the foliage (postemergence). In Mexico, foliar application of herbicides is predominant, which can be either selective or non-selective. Glyphosate is the most widely used herbicide in the country and worldwide; it is a non-selective, non-residual, and systemic product, allowing it to control both annual and perennial weeds (Kanatas *et al*., 2021; Ahuja *et al*., 2024). In the country, this herbicide is used extensively in conservation tillage systems in corn (Monroy-Sais *et al*., 2022), citrus plantations (Palma-Baustista *et al*., 2019) and other fruit trees (Merlo-Reyes *et al*., 2024). It is also applied in glyphosate-resistant cotton crops (Rocha-Munive *et al*., 2018), the only transgenic crop authorised for commercial planting in Mexico.

Paraquat and glufosinate-ammonium are other non-selective herbicides that, in some cases, are used as alternatives to glyphosate to control annual weeds (Orozco and García, 2024). In Mexico, the indiscriminate use of glyphosate has contributed to the development of seven weed biotypes with resistance to this herbicide, six of which are found in citrus orchards and one in the transgenic cotton crop (Domínguez-Valenzuela *et al*., 2017; Arispe-Vázquez *et al*., 2023; Heap, 2025). In addition to the agronomic and economic problems associated with the presence of glyphosate-resistant weed biotypes, glyphosate has been identified as a soil and water contaminant, with its residues posing a risk to both human and animal health (Pérez-Vázquez *et al*., 2024). However, there are still discrepancies among scientists about the magnitude and importance of the problem, as well as the consequences that its possible prohibition could cause (Andreotti *et al*., 2018; Torretta *et al*., 2018; Low, 2020).

On December 31, 2020, the first presidential decree was published, mandating a series of actions for Mexico to phase out the importation and use of the herbicide glyphosate as of April 2024 (SEGOB, 2020). A second decree was published on February 13, 2022 (SEGOB, 2022). Among the activities of the Federal Public Administration implemented by the CONAHCYT (Consejo Nacional de Humanidades, Ciencias y Tecnologías) to comply with the decree, highlights the support to research and diffusion projects to promote an integral ecological management of weeds in Mexico with the most common and successful practices in our country stands out: false sowing, non-living plant covers, living plant covers, brush cutter, power tiller, orchard grazing, crop rotation, high density sowing, polyculture of annuals, agroforestry polyculture, bioherbicides and plastic covers (Urrutia and García, 2024); however, in the absence of viable alternatives for the field; this prohibition was postponed until practical, agroecological and healthy options are found or developed.

Although many pesticides are currently formulated based on natural products, only 7% of conventional herbicides are derived from this type of natural product, despite weeds having the most significant negative impact on crop productivity (Dayan and Duke, 2014). In Mexico, there have been many evaluations of plant extracts or commercial bioherbicides for weed control; however, many studies have been conducted in laboratory conditions, determining good efficiency in inhibiting germination or radicle length of weed seeds (Tejeda-Sartorius and Rodríguez-González, 2008; Cruz-Ortiz and Flores-Méndez, 2021; Miranda-Arámbula *et al.*, 2021), or greenhouse on potted plants (Daniel Gómez and Jiménez Estrada, 2024), which is not necessarily reflected in reasonable weed control in the field.

In addition, to commercialize the extracts, it is required that they are presented in adequate formulations and application methods that allow uniform distribution, without requiring high doses that increase costs (Souza *et al*., 2020). In organic agriculture, certain products are used as herbicides, including corn gluten meal, acetic acid, fatty acids, and essential oils. These products are not very active and are not selective for specific crops, requiring large quantities and complicated application methods to protect the target crop. Consequently, they are restricted to small areas and crops of high economic value (Dayan *et al*., 2009; Cantrell *et al*., 2012).

In Mexico, the commercial availability of bioherbicides is relatively new. Their efficacy depends on several factors related to their bioactive compounds, allelochemical content, stage of plant development, type of formulation, application method, soil type and environmental factors such as light, carbon dioxide, temperature and humidity, so rigorous evaluations are required to know their efficacy and reliability in weed control (Hasan *et al*., 2021). The effectiveness of these herbicides has been highly variable, ranging from null to excellent control. For example, Espinosa-Ramírez and Cisneros-López (2022) determined that the effect of Sec Natural and Herbitech herbicides on weeds was not significantly different from that of the control without application.

According to Esqueda *et al*. (2021; 2022), in orange and Persian lime, Sec Natural and Herbitech showed fair to poor control, so they cannot be considered as alternatives to replace glyphosate. Other authors, such as Orozco and García (2024), concluded that the same herbicides applied at 10 days of weed age were promising for weed control in banana crops, with a biological activity exceeding 90%. In rainfed maize, Schwentesius-Rindermann *et al*. (2024) found that the efficacy of Herbitech and nicosulfuron herbicides was similar, with values of 42% and 41%, respectively; whereas, Zecatryn and 2,4-D amine had values below 25%. Alvarado *et al*. (2016) noted that vinegar, containing acetic acid at a dosage of 20% in 600 L of water, can function as a natural herbicide with efficacy greater than 85% when applied during the early stages of weed phenological development.

The objective of this study was to determine the biological effectiveness of five natural herbicides and three herbicides for the control of monocotyledonous and dicotyledonous weeds in the center of the state of Veracruz.

MATERIALS AND METHODS

The experiment was established on November 7, 2024, in a non-crop plot at the Cotaxtla Experimental Field Station belonging to the Instituto Nacional de Investigaciones Forestales, Agricolas y Pecuarias, located in the municipality of Medellin, Veracruz, Mexico, at coordinates 18°55'56.3" NL and 96°11'31.9" WL, at an altitude of 18 m. The climate of the region was classified as Aw_2, the most humid of the warm sub-humid (Soto *et al*., 2001). A randomised block experimental design with four replications was employed—the experimental units measured 3 m in width by 5 m in length. Nine postemergence treatments were evaluated, consisting of different herbicides, organic herbicides and a control without application (Table 1). Herbicide doses were adjusted according to supplier recommendations. For the application, the nonionic surfactant ADP was added at a dose of 250 mL per 100 L of water. For the Zecatryn and Kill-Herb herbicides, the solution was titrated to a pH of 4. Additionally, molasses, humic acids, and ammonium sulfate were added to Zecatryn at doses of 2 L, 2 L, and 2 kg per 100 L of water.

Table 1. Treatments evaluated at the Campo Experimental Cotaxtla of INIFAP.

No.	Treatment	Dosage	Composition
1	Zecatryn[&#]	200 mL/100 L of water	Penetrating agent 4%, acetic ferment leachate 29%, botanical extracts of aromatic plants 25%, potasic salts of vegetable oils 35%, inerts and diluents 27%.
2	Sec Natural	1500 mL/100 L of water	Confer oil (40%), *Datura stramonium* extract (10%), allelopathic plant extracts (42%), *Puccinia sp.* metabolites (2%) and non-hydrogenated coconut oil.
3	Herbitech	1500 mL/100 L of water	Common mullein 20%, coconut oil 20%, pine resin 20%, *Puccinia fungi* 20% and papain 20%.
4	Kill-Herbs[&]	1000 mL/100 L of water	Organic acids 10%, *Puccinia spp*. metabolites 15%, allelophatic extract of wild plants 5%, enzymes 20%, surfactants, diluents, and conditioners 50%.
5	Vinecide	20000 mL/100 L of water	Acetic acid (98%), citrus x lemon (0.12%), propanol (0.44%) and potassium hydroxide (1.44%).
6	Glyphosate	1089 g active ingredient/ha	Glyphosate monoammonium salt at 41% by weight, and 59% of inert ingredients (surfactant, humectant, and diluent).
7	Paraquat	600 g active ingredient/ha	Paraquat (25%) and inert ingredients (diluent, humectant and stabilizer) (75%).
8	Glufosinate-ammonium	420 g active ingredient/ha	Glufosinate ammonium (18.4%) by weight and inert ingredients (humectant, neutralizing agent and solvent) 81.6%.
9	Control without application	-	

[&]The solution was titrated to a pH of 4. [#] Molasses, humic acids and ammonium sulfate were added in doses of 2 L, 2 L and 2 kg per 100 L of water.

All treatments were applied with a Honda 2525T motorized backpack sprayer, equipped with a boom with four 8003 flat fan nozzles, calibrated to spray 312.5 L of solution per hectare. Only 2.4 m wide plots (12 m^2) were applied, leaving 0.30 m unsprayed strips on each edge (1.5 m^2), which were used as lateral weeded strips at the time of the control evaluations. The weed species present in the experimental site are common in the region and were taxonomically identified by consulting Vibrans (2009) and WFO (2025). To determine the initial density of weeds before the application of treatments, counts were made per weed species using a 1 m^2 square randomly placed in the control plots without treatment application. Additionally, the height of five plants of each dominant species was recorded.

At the time of application, the topsoil had little moisture, but below this, the moisture level was greater than 50% of the field capacity. To evaluate the efficacy of the herbicides in weed control, five evaluations were conducted at 10, 20, 30, 40, and 70 DAA. In each experimental unit, the effect of the treatments was evaluated visually by dominant weed species and grouped weeds, comparing the plants of the treated plots with those of the weeded lateral controls, and assigning a value to the toxicity observed, using a percentage scale (0 to 100%), where zero meant that the weed was not affected and 100% meant that it was eliminated.

To homogenize variances, weed control percentage data were transformed to their sine arc √% values (Frans *et al*., 1986). Analyses of variance were performed on the transformed data, and Tukey's test (α = 0.05) was used to separate the means. The SAS package (SAS Institute Inc., 2015) was used to perform the statistical analyses. Although the analyses of variance and tests of separation of means were carried out with transformed data, for clarity, the percentages of weed control are presented using the original data. Therefore, in the results tables, the value of the minimum significant difference, corresponding to the transformed data, did not always agree with that obtained with the original data.

RESULTS

Nine weed species belonging to eight botanical families were present on the experimental site. The dominant species were purple nutsedge, parthenium weed, Honduras grass and beautyhead, which together occupied 94.15% of the total weed population (Table 2). The average height of the dominant weed species was 9.96 cm for *Cyperus rotundus*, 3.00 cm for *Parthenium hysterophorus*, 12.50 cm for *Ixophorus unisetus* and 6.60 cm for *Baltimora recta*.

In the first evaluation conducted at 10 DAA, no herbicidal effect was observed on any of the species evaluated with the Zecatryn treatment, nor with Vinecide. The lack of herbicidal action of these treatments continued in all remaining evaluations, indicating that they cannot be considered alternatives to replace commercial herbicides commonly used for non-selective weed control. For this same reason, they will not be compared again with treatments that influenced at least one weed species. The glyphosate, paraquat, and glufosinate-ammonium treatments provided total control of *B. recta*, statistically similar to Sec Natural and Herbitech, which in turn were similar to Kill-Herbs, whose controls of this species ranged from 98 to 99%. Total control of *I. unisetus* was achieved with glyphosate, which was not significantly different from the Sec Natural and Herbitech controls, although the latter two were also similar to the control obtained with Kill-Herbs. With paraquat and glufosinate-ammonium, control rates for this species ranged from 75% to 80%. Total control of *P. hysterophorus* was achieved with glyphosate, glufosinate-ammonium, and Herbitech, although their control was not significantly different from that obtained with Sec Natural and Kill-Herbs, both of which were higher than 97%. Paraquat provided inferior control of this species, with less than 10% efficacy. For *C. rotundus*, the highest control was provided by glyphosate, with a value slightly higher than 80%, although the control with paraquat was not significantly different, this was only 70%. Controls between 50 and 70% were provided by glufosinate-ammonium and Sec Natural, while controls below 30% were obtained with Herbitech and Kill-Herbs. The highest control of the entire weed complex was provided by glyphosate with a value slightly above 90%, not significantly different to those provided by Herbitech and glufosinate-ammonium, whose controls ranged from 85 to 90%. With Sec Natural, Kill-Herbs and paraquat, control ranged between 80 and 85% (Table 3).

At 20 DAA, paraquat maintained total control of *B. recta*, with no significant difference from that of glyphosate, glufosinate-ammonium, and Sec Natural, which in turn were also comparable to the control provided by Herbitech. The control obtained with Kill-Herbs was slightly higher than 95%. For *I. unisetus*, glyphosate provided 100% control, although it was not significantly different to Kill-Herbs, Herbitech and Sec Natural, which provided controls greater than 90%, but less than 100%. Glufosinate-ammonium had a control of this species slightly below 80%, while with paraquat, the control was slightly below 70% and was statistically similar. *P. hysterophorus* control was 100% with glyphosate and between 98.5 and 99.5% with Sec Natural, Kill-Herbs, Herbitech and glufosinate-ammonium, treatments that were not significantly different to each other. At the same time, with paraquat, there was no herbicide effect. Glyphosate showed 75% control of *C. rotundus*, which was not significantly different from that provided by paraquat, which was slightly higher at 60%. With glufosinate-ammonium control was 55%, while with Sec Natural it was slightly less than 50%. Herbitech and Kill-Herbs control was only 20%, while Zecatryn had no herbicidal effect.

The highest control of the weed complex was achieved with glyphosate at 90%, which was not significantly different from the 84% and 85% controls obtained with glufosinate-ammonium and Herbitech, respectively. These, in turn, were comparable to the Kill-Herbs and Sec Natural controls, which provided around 80% control. Paraquat had control of 70%. Zecatryn did not affect the weed complex (Table 4).

In the third evaluation, carried out at 30 DAA, glyphosate and paraquat maintained total control of *B. recta*, being not significantly different from the control provided by glufosinate-ammonium, which, in turn, was similar to that obtained with Sec Natural. Controls of this species between 90 and 95% were obtained with Herbitech and Kill-Herbs, which were not significantly different to that provided by Sec Natural. Zecatryn had no effect. Glyphosate and Sec Natural showed the highest controls of *I. unisetus*, being statistically superior to the rest of the treatments. The control with Herbitech was slightly lower than 95%, although not significantly different to Kill-Herbs, which provided a control slightly lower than 90%. Controls slightly above 60% were obtained with paraquat and glufosinate-ammonium, while Zecatryn had no effect on this species.

For *P. hysterophorus* the controls provided by Sec Natural, Herbitech, Kill-Herbs, glufosinate-ammonium and glyphosate showed a variation between 95 and 100% while being statistically similar. The Zecatryn control varied between 30 and 35% and paraquat did not have any effect. At this time of evaluation, the highest control of *C. rotundus* was obtained with glyphosate, which was higher than 60%, although without statistical difference to those provided by paraquat and Sec Natural, which were less than 50%. In the rest of the treatments, the controls varied between 11% (Zecatryn) and 37.5% (glufosinate-ammonium). Combined weed control was most effective with glyphosate, with a value close to 90%. However, this result was statistically like the effects of the Kill-Herbs, Sec Natural, glufosinate-ammonium, and Herbitech treatments, which ranged from 78 to 85%. With paraquat, the control was slightly less than 60%, while with Zecatryn, it was less than 14% (Table 5).

Table 2. Weed species and population density at the experimental site.

Common name	Scientific name	Family	Population density
Purple nutsedge	*C. rotundus* L.	Cyperaceae	700,000
Parthenium weed	*P. hysterophorus* L.	Asteraceae	330,000
Honduras grass	*I. unisetus* (J. Presl) Schltdl.	Poaceae	175,000
Beautyhead	*B. recta* L.	Asteraceae	162,500
Others*			85,000
Total			1’452,500

* Hairy spurge (*Euphorbia hirta* L.) (Euphorbiaceae), erect spiderling (*Boerhavia erecta* L.) (Nyctaginaceae), big caltrop [*Kallstroemia maxima* (L.) Hook. & Arn.] (Zygophyllaceae), tickweed (*Cleome viscosa* L.) (Cleomaceae), Mexican poppy (*Argemone mexicana* L.) (Papaveraceae).

Table 3. Effect of treatments on control by species and total weeds (% and sine arc √% values) at 10 DAA.

Treatmeant	*B. recta*	*I. unisetus*	*P. hysterophorus*	*C. rotundus*	Total
Zecatryn	0.0 (0.0) c	0.0 (0.0) d	0.0 (0.0) c	0.0 (0.0) d	0.0 (0.0) c
Sec Natural	98.7 (84.5) ab	99.5 (87.9) ab	99.7 (88.6) a	55.0 (47.9) b	81.2 (64.7) b
Herbitech	98.7 (84.5) ab	98.5 (83.9) ab	100 (90.0) a	27.5 (31.4) c	87.5 (69.4) ab
Kill-Herbs	98.2 (83.6) b	93.7 (77.5) b	97.5 (85.4) a	25.0 (29.9) c	82.5 (65.3) b
Vinecide	0.0 (0.0) c	0.0 (0.0) d	0.0 (0.0) c	0.0 (0.0) d	0.0 (0.0) c
Glyphosate	100 (90.0) a	100 (90.0) a	100 (90.0) a	81.2 (64.4) a	91.2 (72.9) a
Paraquat	100 (90.0) a	75.0 (60.3) c	6.2 (12.4) b	70.0 (57.1) ab	81.2 (64.5) b
Glufosinate-ammonium	100 (90.0) a	78.75 (62.7) c	100 (90.0) a	65.0 (53.8) bc	86.2 (68.4) ab
Control	0.0 (0.0) c	0 (0) d	0.0 (0.0) c	0.0 (0.0) d	0.0 (0.0) c
MSD	5.9	10.8	9.4	9.4	7.4
CV	2.1	8.9	5.4	23.8	9.2

Letters to the right of control values represent Tukey's test ($p<0.05$). Quantities with the same letter are not statistically different. Comparison is between treatments for each variable. Zecatryn (200 mL/100 L of water), Sec Natural (1500 mL/100 L of water), Herbitech (1500 mL/100 L of water), Kill-Herbs (1000 mL/100 L of water), Vinecide (20000 mL/100 L of water), Glyphosate (1089 g a.i./ha), Paraquat (600 g a.i./ha), Glufosinate-ammonium (420 g a.i./ha), Control (without application), MSD= Minimum significant difference, CV= Coefficient of Variation.

Table 4. Effect of treatments on control by species and total weeds (% and sine arc √% values) at 20 DAA.

Treatment	*B. recta*	*I. unisetus*	*P. hysterophorus*	*C. rotundus*	Total
Zecatryn	0.0 (0.0) d	0.0 (0.0) d	0.0 (0.0) b	0.0 (0.0) e	0.0 (0.0) d
Sec Natural	98.2 (83.4) abc	99.5 (87.9) a	98.5 (85.1) a	47.5 (43.6) c	78.7 (62.7) bc
Herbitech	97.7 (81.9) bc	98.5 (85.0) a	99.0 (85.9) a	20.0 (26.2) d	85.0 (67.3) ab
Kill-Herbs	96.5 (79.5) c	91.2 (75.0) ab	98.7 (86.8) a	20.0 (26.3) d	81.2 (64.4) b
Vinecide	0.0 (0.0) d	0.0 (0.0) d	0.0 (0.0) b	0.0 (0.0) e	0.0 (0.0) d
Glyphosate	99.5 (87.9) ab	100 (90.0) a	100 (90.0) a	75.0 (60.1) a	90.0 (71.6) a
Paracuat	100 (90.0) a	67.5 (55.4) c	0.0 (0.0) b	63.7 (53.4) ab	70.0 (56.9) c
Glufosinate-ammonium	99.5 (87.9) ab	78.7 (66.0) bc	99.5 (87.9) a	55.0 (47.9) bc	84.0 (66.7) ab
Control	0.0 (0.0) d	0.0 (0.0) d	0.0 (0.0) b	0.0 (0.0) e	0.0 (0.0) d
MSD	7.0	18.0	7.5	9.6	6.6
CV	3.7	14.8	6.5	29.4	8.6

Letters to the right of control values represent Tukey's test (p<0.05). Quantities with the same letter are not statistically different. Comparison is between treatments for each variable. Zecatryn (200 mL/100 L of water), Sec Natural (1500 mL/100 L of water), Herbitech (1500 mL/100 L of water), Kill-Herbs (1000 mL/100 L of water), Vinecide (20000 mL/100 L of water), Glyphosate (1089 g a.i./ha), Paraquat (600 g a.i./ha), Glufosinate-ammonium (420 g a.i./ha), Control (without application), MSD= Minimum significant difference, CV= Coefficient of Variation.

Table 5. Effect of treatments on control by species and total weeds (% and sine arc √% values) at 30 DAA.

Treatment	*B. recta*	*I. unisetus*	*P. hysterophorus*	*C. rotundus*	Total
Zecatryn	0.0 (0.0) d	0.0 (0.0) d	32.5 (34.7) b	11.2 (19.5) cd	13.7 (18.9) c
Sec Natural	96.7 (81.0) bc	99.5 (87.9) a	96.2 (82.2) a	40.0 (39.2) abc	80.0 (63.5) a
Herbitech	94.5 (76.9) c	93.7 (75.7) b	97.7 (83.9) a	20.0 (26.2) cd	85.0 (67.5) a
Kill-Herbs	93.5 (75.6) c	89.2 (70.9) b	98.7 (86.8) a	20.0 (26.2) cd	78.2 (62.2) a
Vinecide	0.0 (0.0) d	0.0 (0.0) d	0.0 (0.0) c	0.0 (0.0) d	0.0 (0.0) d
Glyphosate	100 (90.0) a	100 (90.0) a	100 (90.0) a	61.2 (51.6) a	89.5 (71.1) a
Paraquat	100 (90.0) a	61.2 (51.6) c	0.0 (0.0) c	45.0 (42.0) ab	57.5 (49.4) b
Glufosinate-ammonium	99.50 (87.9) ab	62.5 (52.3) c	99.5 (87.9) a	37.5 (37.7) bc	80.0 (63.5) a
Control	0.0 (0.0) d	0 (0) d	0.0 (0.0) c	0.0 (0.0) d	0.0 (0.0) d
MSD	7.0	7.9	10.9	13.3	12.8
CV	5.9	10.5	6.6	42.8	11.9

Letters to the right of control values represent Tukey's test (p<0.05). Quantities with the same letter are not statistically different. Comparison is between treatments for each variable. Zecatryn (200 mL/100 L of water), Sec Natural (1500 mL/100 L of water), Herbitech (1500 mL/100 L of water), Kill-Herbs (1000 mL/100 L of water), Vinecide (20000 mL/100 L of water), Glyphosate (1089 g a.i./ha), Paraquat (600 g a.i./ha), Glufosinate-ammonium (420 g a.i./ha), Control (without application), MSD= Minimum significant difference, CV= Coefficient of Variation.

At 40 DAA, the most effective treatments for *B. recta* control showed efficacy rates between 98 and 100% with paraquat, glyphosate and glufosinate-ammonium. The Sec Natural treatment provided a control slightly higher than 95%, being like the results of two of the three treatments indicated above. On the other hand, Kill-Herbs and Herbitech had a control between 90 and 95%. In contrast, Zecatryn showed no effect. For *I. unisetus*, the glyphosate and Sec Natural treatments achieved a control of more than 99%, being statistically superior to the rest of the treatments. With Kill-Herbs and Herbitech, a control of between 80 and 90% was obtained, showing statistical similarity between them and surpassing paraquat and glufosinate-ammonium, which had a control between 50 and 55%. Zecatryn had no effect on this species.

The highest control rates of P. hysterophorus were obtained with glyphosate, glufosinate-ammonium, Herbitech, Kill-Herbs, and Sec Natural, with values ranging from 94 to 100%, indicating statistical similarity among them. In contrast, Zecatryn only achieved a control rate of 25%. Paraquat had no effect. For *C. rotundus*, all treatments showed less than 50% control, with the highest controls being provided by glyphosate and paraquat, whose values were between 40 and 50%, statistically similar to that of Sec Natural. Overall weed control was maintained at values between 80 and 90% with glyphosate and Sec Natural, although statistically, they were similar to the controls, which ranged between 70 and 80% provided by Herbitech, Kill-Herbs, and glufosinate-ammonium. With paraquat, the control was 50%, while with Zecatryn it was less than 15% (Table 6).

Table 6. Effect of treatments on control by species and total weeds (% and sine arc √% values) at 40 DAA.

Treatment	*B. recta*	*I. unisetus*	*P. hysterophorus*	*C. rotundus*	Total
Zecatryn	0.0 (0.0) e	0.0 (0.0) d	25.0 (29.9) b	10.0 (18.4) cd	13.75 (21.5) c
Sec Natural	95.5 (79.7) bcd	99.5 (87.9) a	94.2 (80.2) a	37.5 (37.7) ab	80.00 (63.5) a
Herbitech	94.5 (76.9) cd	88.0 (70.0) b	97.0 (82.9) a	15.0 (19.5) bc	79.50 (63.3) a
Kill-Herbs	91.2 (73.2) d	83.7 (66.4) b	95.5 (80.9) a	8.7 (12.3) cd	73.75 (59.2) a
Vinecide	0.0 (0.0) e	0.0 (0.0) d	0.0 (0.0) c	0.0 (0.0) d	0.0 (0.0) d
Glyphosate	99.5 (87.9) ab	99.7 (88.6) a	100 (90.0) a	47.5 (43.6) a	87.00 (68.9) a
Paraquat	100 (90.0) a	50.0 (45.0) c	0 (0) c	40.0 (38.7) a	50.00 (45.0) b
Glufosinate-ammonium	98.7 (86.8) abc	53.7 (47.2) c	98.2 (84.7) a	22.5 (27.3) abc	76.25 (61.1) a
Control	0.0 (0) e	0.0 (0.0) d	0.0 (0.0) c	0.0 (0.0) d	0.0 (0.0) d
MSD	10.1	12.5	13.4	18.9	9.9
CV	7.7	19.3	8.9	66.3	15.5

Letters to the right of control values represent Tukey's test ($p<0.05$). Quantities with the same letter are not statistically different. Comparison is between treatments for each variable. Zecatryn (200 mL/100 L of water), Sec Natural (1500 mL/100 L of water), Herbitech (1500 mL/100 L of water), Kill-Herbs (1000 mL/100 L of water), Vinecide (20000 mL/100 L of water), Glyphosate (1089 g a.i./ha), Paraquat (600 g a.i./ha), Glufosinate-ammonium (420 g a.i./ha), Control (without application), MSD= Minimum significant difference, CV= Coefficient of Variation.

At 70 DAA, control rates of *B. recta* between 90 and 95% were obtained with glufosinate-ammonium and paraquat, which were not significantly different from the controls between 80 and 90% provided by Sec Natural, Herbitech, and glyphosate. Zecatryn did not affect this species. For *I. unisetus* there was a control slightly higher than 90% with glyphosate, not significantly different to Sec Natural, which was slightly lower than 90%, and to Herbitech. Kill-Herbs, paraquat and glufosinate-ammonium had controls between 25 and 50%, while Zecatryn showed no effect on this grass. The highest control of *P. hysterophorus* was achieved with glyphosate, at 98.75%, although it showed statistical similarity with Herbitech, Sec Natural, and glufosinate-ammonium, whose values fluctuated between 85% and 95%. With Kill-Herbs, the control was slightly lower than 80%, which was statistically similar to the control rates of the last three herbicides mentioned. The Zecatryn control was lower than 10%, while paraquat did not affect this species. The only treatments that showed some effect on *C. rotundus* were glyphosate, paraquat, Sec Natural, and glufosinate-ammonium; however, the controls were very poor, with a maximum value of 20%. Overall weed control was slightly above 80% with glyphosate, which was not significantly different to Sec Natural, which registered a value slightly above 70%. Controls between 60 and 65% were obtained with Kill-Herbs, Herbitech and glufosinate-ammonium, while with the rest of the treatments, controls were lower than 35% (Table 7).

Table 7. Effect of treatments on control by species and total weeds (% and sine arc √% values) at 70 DAA.

Treatment	*B. recta*	*I. unisetus*	*P. hysterophorus*	*C. rotundus*	Total
Zecatryn	0.0 (0.0) c	0.0 (0.0) d	7.5 (13.8) c	0.0 (0.0) b	3.7 (9.7) d
Sec Natural	85.0 (70.3) ab	88.7 (70.8) a	91.2 (77.7) ab	10.0 (12.9) ab	71.2 (57.6) ab
Herbitech	88.7 (70.91) ab	65.0 (54.2) ab	88.7 (73.5) ab	0.0 (0.0) b	63.7 (53.1) b
Kill-Herbs	71.2 (57.84) bc	50.0 (44.9) bc	77.5 (61.8) b	0.0 (0.0) b	60.0 (50.8) b
Vinecide	0.0 (0.0) c	0.0 (0.0) d	0.0 (0.0) c	0.0 (0.0) b	0.0 (0.0) d
Glyphosate	88.7 (70.9) ab	91.2 (72.9) a	98.7 (86.8) a	20.0 (26.6) a	82.5 (65.3) a
Paraquat	95.0 (78.9) a	42.5 (40.4) bc	0.0 (0.0) c	12.5 (14.9) ab	32.5 (34.5) c
Glufosinate-ammonium	92.5 (74.3) a	25.0 (22.5) cd	92.5 (78.7) ab	2.5 (4.6) b	63.7 (53.1) b
Control	0.0 (0.0) c	0.0 (0.0) d	0.0 (0.0) c	0.0 (0.0) b	0.0 (0.0) d
MSD	14.5	24.3	21.8	20.0	10.0
CV	3.7	14.8	6.5	29.4	8.7

Letters to the right of control values represent Tukey's test ($p<0.05$). Quantities with the same letter are not statistically different. Comparison is between treatments for each variable. Zecatryn (200 mL/100 L of water), Sec Natural (1500 mL/100 L of water), Herbitech (1500 mL/100 L of water), Kill-Herbs (1000 mL/100 L of water), Vinecide (20000 mL/100 L of water), Glyphosate (1089 g a.i./ha), Paraquat (600 g a.i./ha), Glufosinate-ammonium (420 g a.i./ha), Control (without application), MSD= Minimum significant difference, CV= Coefficient of Variation.

DISCUSSION

The trial was conducted in the autumn-winter agricultural cycle, which is very important in the state of Veracruz, due to the practice of double cropping of corn in relay of beans and corn in succession of corn, where soil preparation is done exclusively with herbicides, mainly glyphosate or paraquat, before planting the second crop.

Glyphosate demonstrated the highest efficiency in controlling most of the weed species present in this study. Although the final evaluation did not show a significant difference from Sec Natural, there was a notable difference in control of more than 10% in favour of glyphosate between the two treatments. In addition, glyphosate had the greatest control of *C. rotundus*, a perennial monocotyledonous species.

Sec Natural, which was the most efficient organic herbicide for weed control in this work, in the state of Colima, it also showed similar controls to those of glyphosate (between 80 and 95%) in banana (Orozco and García, 2024) and Persian lime (García and Orozco, 2021); however, in orange and Persian lime crops in the state of Veracruz, 30 days after application, weed controls ranged from fair to poor (30 to 62.5%), not comparable with those obtained with glyphosate which recorded average values of around 90% (Esqueda *et al*., 2021; Esqueda *et al*., 2022). Moreover, in the north of Tamaulipas, applied in pre-sowing, as usual in corn and sorghum crops, at 22 DAA, this herbicide only had an average control of dicotyledonous and monocotyledonous weeds of about 16%. In contrast, with glyphosate the average control was slightly higher than 96% (Hernández *et al*., 2021). Differences in weed control efficiency in different locations may be due to the rate applied, the size of the weeds, soil moisture at the time of application or the presence of species with natural tolerance or perennial, so it is indispensable that, if you want to use a natural or chemical herbicide different from the one commonly used, an application of the new herbicide on a small area should be made previously, and thus determine whether it is efficient for controlling the weed species present in the plot.

The response of the other organic herbicides was highly variable; for example, Herbitech had average controls similar to those of glyphosate up to 40 DAA, but at 70 DAA, its efficiency was approximately 20% lower than that of glyphosate. In corn, Schwentesius-Rindermann *et al*. (2024) found that Herbitech provided only 42% weed control, whereas in Persian lime, control rates ranged from 62.5 to 80%, and in orange, from 14 to 35% (Esqueda *et al*., 2021, 2022). With Kill-Herbs, efficient control of annual weeds was obtained up to 40 DAA. There is no published information on its effectiveness in controlling weeds in different crops, but according to the results obtained in this experiment, it could be a suitable alternative for the control of annual weeds, always making a previous test on the weed species in the field. The effects of Zecatryn were only observed on two weed species after the third evaluation; however, its control values were extremely poor, similar to those reported by Schwentesius-Rindermann *et al*. (2024). In addition, the label of this product indicates that it should be added to a solution containing humic acids, molasses, and ammonium sulfate at pH 4, which makes its preparation and application impractical and costly.

There are several works in where it was determined that vinegar in high concentration can be successfully used as a non-selective herbicide, by itself (Alvarado *et al*., 2016; Webber III *et al*., 2018), as in a mixture with other organic compounds (Rahayuningsih and Supriadi, 2014); generally it is most effective on dicotyledonous weeds, so that eventually, in later crop cycles, monocotyledonous weeds (grasses and sedges) could replace dicotyledonous weeds in the plot, making the application of a different compounds necessary for its control. In addition, because it is used in high doses with higher concentrations than commercial vinegar, there is a high risk of damage to the skin or eyes of the applicator (Forsburg, 2007) and it is an expensive treatment, suitable only for organic farming, whose effect is drastically reduced between the first and second week after application. In this experiment, Vinecide, which is formulated with 20% acetic acid (in contrast to cooking vinegar, which contains only 5% acetic acid), showed no effect on any of the weed species, which was also reported by Rebolledo *et al*. (2019); in pineapple under rainfed conditions. Since most studies evaluating vinegar indicate that this product has herbicidal activity, it is suggested that further studies be conducted, varying the doses applied, the agricultural growth cycle, and the species and size of weeds (Alvarado *et al*., 2016; Tse-Seng *et al*., 2022).

With respect to the other synthetic herbicides, paraquat only controls annual weed species and there can be much variation in its effectiveness according to the species on which it is applied; in this case, it was very efficient in controlling *B. recta* up to 70 DAA, but did not affect *P. hysterophorus*, a species with natural tolerance to this herbicide, which has been previously documented (Asghar *et al*., 2021). Additionally, this herbicide is classified as an environmental pollutant and is extremely toxic; therefore, extreme care must be taken during its application (Wen-Tien, 2013). Like paraquat, glufosinate-ammonium also controls only annual weeds. However, it is more efficient on dicotyledonous weeds than on *I. unisetus*, and outperforms paraquat in total weed control, which coincides with the results obtained by Wibawa *et al*.

(2010) in weed control studies in an oil palm plantation in Malaysia.

In general, synthetic herbicides are formulated according to well-structured industrial processes, which guarantee a uniform concentration and quality, which is reflected in greater consistency in weed control; in addition, the active ingredients and their mode and mechanism of action are well determined, so it is to some extent possible to predict their performance and selectivity. In contrast, natural herbicides generally contain compounds defined in a more general way, such as botanical extracts of aromatic or allelopathic plants, without specifying the species, or extracts of specific plants, but without identifying the secondary metabolites or molecules that cause the herbicidal effects, or the contents of the allelopathic compounds that vary with the type and age of the plants used in the preparation of herbicides (Hasan *et al*., 2021). Therefore, there may be cases in which a plot produced at a specific period may have differences in the concentration of the components compared to another plot produced at a later period. The inconsistency in the efficiency of natural herbicides is one of the reasons they are limited in their use as a substitute for glyphosate, despite some cases of successful weed control. Other factors influencing the efficacy of natural herbicides are: water quality (Hasan *et al*., 2021), which generally require low pH to ensure their effectiveness; environmental conditions before and after application, which influence the infection process of some pathogens or their metabolites, as is the case of *Puccinia*, present in three of the herbicides evaluated in this study and which requires a prolonged period of dew after application for massive inoculum production (Morales-Payan *et al*., 2005).

It is necessary to point out that natural herbicides are essentially non-selective and have a contact action, so they are more effective against small weeds. They are typically restricted to applications in fruit or forest plantations, or in unplanted areas, such as vacant lots, roadsides, etc. In annual or horticultural crops, they should be applied at pre-sowing or pre-emergence, or in applications directed to the weeds, taking care not to touch the foliage of the cultivated plants. Additionally, the fact that they are herbicides of natural origin does not necessarily mean they are harmless to applicators or the environment (Loddo *et al*., 2021). It is important to note that the results presented here may not necessarily be similar to those of other weed species and under other agroclimatological conditions. The current limitations of natural herbicides can be considered research opportunities to identify plant species and microorganisms with herbicidal activity, for the formulation of products that allow their commercialization; priority should be given to the determination of the active ingredient(s), as well as their modes and mechanisms of action, for their future synthesis and thus improve their effectiveness and consistency in weed control (Rojas and Gámez, 2002).

CONCLUSIONS

For natural herbicides, the following is concluded: 1. Sec Natural and Herbitech had a total efficacy of about 80%, not significantly different from glyphosate up to 40 DAA. However, its effect on *C. rotundus* was lower. 2. Kill-Herbs recorded fair to good efficacy on all weed species up to 40 DAA, except on *C. rotundus*, its effect being like that of Sec Natural and Herbitech. 3. Zecatryn only showed very slight effects on *P. hysterophorus* and *C. rotundus* after 30 DAA, although its control of all weeds was always less than 15%. 4. Vinecide showed no herbicidal effect on any weed species at any evaluation date. 5. Kill-Herbs, Herbitech and Sec Natural could be good alternatives for use in the control of *B. recta*, *I. unisetus* and *P. hysterophorus*.

In turn, for synthetic herbicides it is concluded that: 1. Glyphosate registered the best effectiveness in the control of the whole set of weeds, which was slightly higher than 80% at 70 DAA, with *C. rotundus* being the species in which it provided the least effectiveness. 2. Glufosinate-ammonium had controls like those of glyphosate up to 40 DAA, except with *I. unisetus*, whose control was always lower. 3. Paraquat had efficient control of *B. recta* at all times of evaluation. Still, its effect was fair or poor in the rest of the species, highlighting that it did not affect P. hysterophorus. Hence, its effectiveness was less than that of glufosinate-ammonium and glyphosate.

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editing; **R. Zetina-Lezama** – Funding acquisition, project administration, resources, supervisión, writing – review & editing; **M.A. Reynolds-Chávez** – Writing – original draft; **N. Peralta-Antonio** – Writing – original draft.

REFERENCES

Ahuja, M., Kumar, L., Kumar, K., Shingatgeri, V. M. and Kumar, S. 2024. Glyphosate: a review on its widespread prevalenceand occurrence across various systems. Environmental Sciences: Advances 3(7), pp. 1030-1038. https://doi.org/10.1039/d4va00085d

Alvarado, A., Carrera, D. and Yance, G., 2016. Estudio del impacto en el control natural de malezas a partir del vinagre. *Revista Caribeña de Ciencias Sociales*, [en línea] disponible en http://www.eumed.net/rev/caribe/2016/12/vinagre.html [consulta: 7 abril 2025].

Andreotti, G., Koutros, S., Hofmann, J.N., Sandler, D.P., Lubin, J.H., Lynch, C.F., Lerro, C.C., De Roos, A.J., Parks, C.G., Alavanja, M.C., Silverman, D.T. and Freeman, L.E.B., 2018. Glyphosate use and cancer incidence in the agricultural health study. *Journal of the National Cancer Institute*, 110(5), pp. 509-516. https://doi.org/10.1093/jnci/djx233

Arispe-Vázquez, J.L., Cadena-Zamudio, D.A., Tamayo Esquer, L.M., Noriega-Cantú, D.H., Toledo-Aguilar, R., Felipe-Victoriano, M., Barrón-Bravo, O.G., Reveles-Hernández, M., Ramírez-Sánchez, S.E. and Espinoza-Ahumada, C.A., 2023. A review of the current panorama of glyphosate resistance among weeds in Mexico and the rest of the world. *Agro Productividad*, 16(7), pp. 135-149. https://doi.org/10.32854/agrop.v16i7.2618

Asghar, M., Baig, M.M.Q., Latif, M.T. and Hussain, M., 2021. Evaluation of the effect of different herbicides for the control of parthenium weed. *Turkey Journal of Weed Science*, 24(1), pp. 19-28. [en línea] disponible en https://dergipark.org.tr/en/download/article-file/1121932 [consulta: 7 abril 2025].

Beckie, H.J., Flower, K.C. and Ashworth, M.B., 2020, Farming without glyphosate? *Plants*, 9(1), 96. https://doi.org/10.3390/plants9010096

Cantrell, C.L., Dayan, F.E. and Duke, S.O., 2012. Natural products as sources for new pesticides. *Journal of Natural Products*, 75(6), pp.1231-1242. https://doi.org/10.1021/np300024u

Colbach, N., Petit, S., Chauvel, B., Deytieux, V., Lechenet. M., Munier-Jolain, N. and Cordeu, S. 2020. The pitfalls of relating weed, herbicide use, and crop yield; don' fall into the trap! A critical review. Frontiers in Agronomy, 2, pp. 615470. https://doi.org/10.3389/fagro.2020.615470

Cruz-Ortiz, L. and Flores-Méndez, M., 2021. Avances en el desarrollo de nuevos herbicidas biológicos a partir de extractos vegetales fitotóxicos aplicados in vitro. *Informador Técnico*, 86(1), pp. 34-45. https://doi.org/10.23850/22565035.3648

Daniel Gómez, A.E. and Jiménez Estrada, S.N., 2024. *Formulación de nanoherbicidas a partir de D-Limoneno para su evaluación en malezas bajo invernadero*. Tesis de licenciatura no publicada. Tlajomulco de Zúñiga, Jal., Mexico: Instituto Tecnológico de Tlajomulco.

Dayan, F.E., Cantrell, C.L. and Duke, S.O., 2009. Natural products in crop protection. *Bioorganic & Medicinal Chemistry*, 17(12), pp. 4022-4034. https://doi.org/10.1016/j.bmc.2009.01.046

Dayan, F.E. and Duke, S.O., 2014. Natural compounds as next-generation herbicides. *Plant Physiology*, 166(3), pp. 1090-1105. https://doi.org/10.1104/pp.114.239061

Domínguez-Valenzuela, J.A., Gherekhloo, J., Fernández-Moreno, P.T., Cruz-Hipólito, H.E., Alcántara-de la Cruz, R., Sánchez-González, E. and De Prado, R., 2017. First confirmation and characterization of target and non-target site resistance to glyphosate in Palmer amaranth (*Amaranthus palmeri*) from Mexico. *Plant Physiology and Biochemistry*, 115, pp. 212-218. https://doi.org/10.1016/j.plaphy.2017.03.022

Espinosa-Ramírez, M. and Cisneros-López, M.E., 2022. Herbicidas orgánicos alternativa al glifosato para el control de maleza en presiembra en el norte de Tamaulipas. *Avances en Investigación Agropecuaria*, 26, pp. 13-14. https://doi.org/10.53897/RevAIA.22.26.16

Esqueda, E.V.A., Enríquez, Q.J.F. and Matilde, H.C., 2022. Alternativas al glifosato para el control de malezas en cítricos en el estado de Veracruz: Resultados en 2021. In: J.C. Delgado-Castillo, E. Rosales-Robles y J.C. Delgado-Tinoco. (eds.). *Memorias del XLIII Congreso Nacional de la Ciencia de la Maleza*. Celebrado el 22-24 noviembre 2022 (virtual). Sociedad Mexicana de la Ciencia de la Maleza, 97-106.

Esqueda, E.V.A., Enríquez, Q.J.F., Matilde, H.C. and Díaz, Z.U.A., 2021. Alternativas al glifosato para el control de malezas en limón persa en el estado de Veracruz. In: J.C. Delgado-Castillo, E. Rosales-Robles y J.C. Delgado-Tinoco. (eds.). *Memorias del XLII Congreso Nacional de la Ciencia de la Maleza*. Celebrado el 23-25 noviembre 2021 (virtual). Sociedad Mexicana de la Ciencia de la Maleza, pp. 228-235.

Esqueda-Esquivel, V.A., Tosquy-Valle, O.H., Ramírez-Vera, A.R. and Andrés-Meza. P., 2025. Effectiveness of fomesafen alone and its mixtures for weed control in bean crops. *Agro Productividad*, 18(2), pp. 125-134. https://doi.org/10.32854/agrop.v18i2.3250

Esqueda-Esquivel, V.A., Uresti-Durán, D. and Hernández-Aragón, L., 2015. Alternativas al fenoxaprop-etil para el control del zacate Johnson *Sorghum halepense* (L.) Pers. en arroz de riego. *Ecosistemas y Recursos Agropecuarios*, 2(6), pp. 317-325. http://dx.doi.org/10.19136/era.a2n6.294

Fonteyne, S., Leal Gonzalez, A. J., Osorio Alcalá, L., Villa Alcántara, J., Santos Rodriguez, C., Núñez Peñaloza, O., Ovando Galdámez, J. R., Singh, R. G. and Verhulst, N. 2022. Weed management and tillage effect on rainfed maize production in three agro-ecologies in Mexico. Weed Research, 62, pp. 224-239. https://doi.org/10.1111/wre.12530

Forsburg, F. 2007. Vinegar as an herbicide in organic garlic production. [en línea] disponible en https://projects.sare.org/media/pdf/8/7/9/879405fne03-461-final-report.pdf [consulta: 9 abril 2025].

Frans, R.E., Talbert, R., Marx, D. and Crowley, H., 1986. Experimental design and techniques for measuring and analyzing plant responses to weed control practices. In: N. D. Camper, ed. *Research Methods in Weed Science*. Southern Weed Science Society. pp. 29-46.

García, M.K. and Orozco, S.M., 2021. Efectos de herbicidas agroecológicos para el control de malezas en limón mexicano (*Citrus aurantifolia*) en Tecomán, Colima. In: J.C. Delgado-Castillo, E. Rosales-Robles y J.C. Delgado-Tinoco (eds.). *Memorias del XLII Congreso Nacional de la Ciencia de la Maleza*. Celebrado el 23-25 noviembre 2021 (virtual). Sociedad Mexicana de la Ciencia de la Maleza, 122-129.

Gharde, Y., Singh, P.K., Dubey, R.P. and Gupta, P.K., 2018. Assessment of yield and economic losses in agriculture due to weeds in India. *Crop Protection*, 107, pp. 12-18. https://doi.org/10.1016/j.cropro.2018.01.007

Hasan, M., Ahmad-Hamdani, M.S., Rosli, A.M. and Hamdan, H., 2021. Bioherbicides: an eco-friendly tool for sustainable weed management. *Plants*, 10(6), pp. 1212. https://doi.org/10.3390/plants10061212

Heap, I. 2025. The International Herbicide-Resistant Weed Database. [en línea] disponible en http://weedscience.org/Pages/filter.aspx [consulta: 9 abril 2025].

Hernández, M.R., Rosales, R.E., Espinosa, R.M. and Cisneros, L.M.E., 2021. Efectividad de herbicidas alternativos a glifosato en el control de malezas en el norte de Tamaulipas. In: J.C. Delgado-Castillo, E. Rosales-Robles y J.C. Delgado-Tinoco (eds.). *Memorias del XLII Congreso Nacional de la Ciencia de la Maleza*. Celebrado el 23-25 noviembre 2021 (virtual). Sociedad Mexicana de la Ciencia de la Maleza, 259-266.

Horvath, D.P., Clay, S.A., Swanton, C.J. Anderson, J.V. and Chao, W.S., 2023. Weed-induced crop yield loss: a new paradigm and new challenges. *Trends in Plant Science*, 28(5), pp. 567-582. https://doi.org/10.1016/j.tplants.2022.12.014

Kanatas, P., Antonopoulos, N., Gazoulis. I. and Travlos, I. S. 2021. Screening glyphosate-alternative weed control options in important perennial crops. Weed Science 69(6), pp. 704-718. https://doi.org/10.1017/wsc.2021.55

Loddo, D., McElroy, J.S. and Giannini, V., 2021. Problems and perspectives in weed management. *Italian Journal of Agronomy*, 16(4), 1854. https://doi.org/10.4081/ija.2021.1854

Low, T., 2020. Glyphosate: a chemical to understand. Invasive Species Council. [en línea] disponible en https://invasives.org.au/wp-content/uploads/2020/11/Glyphosate-A-Chemical-to-Understand.pdf [consulta: 10 abril 2025].

Medina-Cázares, T., Solís-Moya, E. Grageda-Cabrera, O.A. and González-Figueroa, S.S., 2024. Narrow and broadleaf weed control in wheat. *Revista Mexicana de Ciencias Agrícolas*, 5(6), pp.e3105. https://doi.org/10.29312/remexca.v15i6.3105

Merlo-Reyes, A., Baduel, C., Duwig, C. and Ramírez, M.I., 2024. Risk assessment of pesticides used in the eastern avocado belt of Michoacan, Mexico: A survey and water monitoring approach. *Science of The Total Environment*, 916, pp.170288. https://doi.org/10.1016/j.scitotenv.2024.170288

Miranda-Arámbula, M., Reyes-Chilpa, R. and Anaya, L.A.L., 2021. Phytotoxic activity of aqueous extracts of ruderal plants and its potential application to tomato crop. *Botanical Sciences*, 99(3), pp. 487-498. https://doi.org/10.17129/botsci.2727

Monroy-Sais, A.S., Astier, M., Wies, G., Pavesi, R., Mascorro-de Loera, D. and García-Barrios, L., 2022. Exploring the complexity of smallholders' intense use of glyphosate in maize crops from South Mexico: Remarks for an ongoing agroecological transition. *Frontiers in Sustainable Food Systems*, 6, pp.908779. https://doi.org/10.3389/fsufs.2022.908779

Morales-Payan, J.P., Charudattan, R. and Stall, W.M., 2005. Fungi for biological control of weedy cyperaceae, with emphasis on purple and yellow nutsedges (*Cyperus rotundus* and *C. esculentus*). *Pest Management*, 16(4), pp.148-155. https://doi.org/10.1564/16aug02.

Orozco, S.M. and García, M.K., 2024. Evaluación de alternativas químicas y orgánicas al herbicida glifosato para el control de maleza en el cultivo de banano. *Acrobat Revista de Tecnología y Ciencia*, 1(1), pp.67, https://doi.org/10.62498/ARTC.2467

Palma-Bautista, C., Gherekhloo, J., Domínguez-Martínez, P.A., Domínguez-Valenzuela, J. A., Cruz-Hipólito, H.E., Alcántara- de la Cruz, R., Rojano-Delgado, A.M. and De Prado, R., 2019. Characterization of three glyphosate resistant *Parthenium hysterophorus* populations collected in citrus groves from Mexico. *Pesticide Biochemistry and Physiology*, 155, pp. 1-7. https://doi.org/10.1016/j.pestbp.2018.11.002

Pérez-Vázquez, A., Fernández-Peña, M.L., Castañeda-Chávez, M.R. and Díaz-Rivera, P., 2024. Glifosato: riesgo o amenaza para la salud humana y la vida silvestre. *Revista Mexicana de Ciencias Agrícolas*, 15(5), e3342. https://doi.org/10.29312/remexca.v15i5.3342

Quintero-Pertúz, I. and Carbonó-De la Hoz, E., 2016. Panorama del manejo de malezas en cultivos de banano en el departamento del Magdalena, Colombia. *Revista Colombiana de Ciencias Hortícolas*, 9 (2), pp. 329-340. https://doi.org/10.17584/rcch.2015v9i2.4188

Rahayuningsih, S. and Supriadi, S., 2014. Herbicidal efficacy of acetic acid and citric acid base on broad leaf weeds of medicinal crops fields. *Buletin Penelitian Tanaman Rempah dan Obat*, 25(2), pp. 137-143. https://doi.org/10.21082/bullittro.v25n2

Rebolledo, M.L., Rebolledo, M.A., Montiel, V.G., López, V.M.E., Peralta, A.N., Rebolledo, G.R.L. and Uriza, Á.D.E., 2019. Herbicidas convencionales y orgánicos para control de malezas en el cultivo de piña. In: *Avances en Investigación Agrícola, Pecuaria, Forestal, Acuícola, Pesquería, Desarrollo Rural, Transferencia de Tecnología, Biotecnología, Ambiente, Recursos naturales y Cambio climático*. Vinay, V.J.C., Esqueda, E.V.A., Tosquy, V.O.H., Zetina, L.R., Ríos, U.A., Vázquez, H.M.V, Del Angel, P.A.L. y Perdomo, M.C. (comps.). Medellín, Ver., Mexico: Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, 201-210.

Rocha-Munive, M.G., Soberón, M., Castañeda, S., Niaves, E., Scheinvar, E., Eguiarte, L.E., Mota-Sánchez, D., Rosales-Robles, E., Nava-Camberos, U., Martínez-Carrillo, J.L., Blanco, C.A., Bravo, A. and Souza, V., 2018. Evaluation of the impact of genetically modified cotton after 20 years of cultivation in Mexico. *Frontiers in Bioengineering and Biotechnology*, 6, pp.82. https://doi.org/10.3389/fbioe.2018.00082

Rojas, G.M. and Gámez, G.H., 2002. Herbicidas de origen natural. *Ciencia UANL*, 5(2), pp.160-164. [en línea] disponible en https://www.redalyc.org/pdf/402/40250204.pdf [consulta: 9 abril 2025].

SAS Institute Inc. 2015. SAS/STAT 9.4: User's Guide. Cary, NC: SAS Institute Inc.

SEGOB (Secretaría de Gobernación). 2020. Diario Oficial de la Federación. Secretaría de Gobernación. [en línea] disponible en http://www.dof.gob.mx/nota_detalle.php?codigo=5609365&fecha=31/12/2020 [consulta: 8 abril 2025].

SEGOB (Secretaría de Gobernación). 2022. Diario Oficial de la Federación. Secretaría de Gobernación. [en línea] disponible en https://www.dof.gob.mx/nota_detalle.php?codigo=5679405&fecha=13/02/2023#gsc.tab=0 [consulta: 8 abril 2025].

Schwentesius-Rindermann, R., Dámaso-Lara, N. and Hernández-Vázquez, B., 2024. Comparación de bioherbicidas y herbicidas sintéticos en San Juan Tezontla, Texcoco de Mora, Mexico. In: H.E. Alvarado-Raya, J. Martínez-Solís y N. Magaña-Lira. (eds.). *Memorias del XII Congreso Internacional y XXVI Congreso Nacional de Ciencias Agronómicas*. Celebrados el 23-26 abril 2024. Universidad Autónoma Chapingo, 259-260.

Soto, M., Gama, L. and Gómez, M., 2001. Los climas cálidos subhúmedos del estado de Veracruz, Mexico. *Foresta Veracruzana*, 3(2), pp. 31-40.

Souza, B.V.M. de, Ferreira, P.J.L., Ribeiro, G.D., Carvalho, L.M.F., Rodrigues, C.G., Gonçalves, A.H. and Quinute, T.P.V.V., 2020. Herbicides of biological origin: a review. *The Journal of Horticultural Science and Biotechnology*, 96(3), pp. 288-293. https://doi.org/10.1080/14620316.2020.1846465

Tejeda-Sartorius, O. and Rodríguez-González, M.T., 2008. Inhibidores de germinación y crecimiento de maleza y hortalizas, en residuos de amaranto (*Amaranthus hypochondriacus* L.). *Agrociencia*, 42(4), pp. 415-423.

Torretta, V., Katsoyiannis, I.A., Viotti, P. and. Rada, E.C., 2018. Critical review of the effects of glyphosate exposure to the environment and humans through the food supply chain. *Sustainability*, 10(4), 950. https://doi.org/10.3390/su10040950

Tse-Seng, G., Nasarrudin, A. R. M., Masilamany, D., Chai, K., Byung-Woo, L., Arifin, M. F. and Sang-Sun, L., 2022. Effect of surfactant and different spray volumes on the efficacy of acetic acid based natural herbicide for controlling Imperata cylindrica and Sporobolus indicus. Plant Omics Journal, 15(01), pp. 1-5. http://doi.org/10.21475/POJ.15.01.22.p3371

Urrutia, C.A.L. and García, B.L.E., (Coords.). 2024. Manejo Ecológico Integral de Arvenses en Mexico (MEIA). Compilado de Gacetas 1 a 27. [en línea] disponible en. https://secihti.mx/wp-content/uploads/publicaciones_conacyt/boletines_tematicos/Gaceta_MEIA_imprenta_1-27.pdf [consulta: 10 abril 2025].

Vibrans, H. (ed.) 2009. Malezas de Mexico. [en línea] disponible en https://www.conabio.gob.mx/malezasdemexico/2inicio/home-malezas-mexico.htm [consulta: 17 septiembre 2025].

Webber III, C.L., White Jr., P.M., Shrefler, J.W. and Spaunhorst, D.J., 2018. Impact of acetic acid concentration, application volume, and adjuvants on weed control efficacy. *Journal of Agricultural Science*, 10(8), pp. 1-1. https://doi.org/10.5539/jas.v10n8p1

Wen-Tien, T., 2013. A review on environmental exposure and health risks of herbicide paraquat. *Toxicological and Environmental Chemistry*, 95(2), pp. 197-206. https://doi.org/10.1080/02772248.2012.761999

WFO (The Worls Flora OnLine). 2025. *Baltimora recta* L. [en línea] disponible en http://www.worldfloraonline.org/taxon/wfo-0000036140 [consulta: 17 septiembre 2025].

Wibawa, W., Mohayidin, M.G., Mohamad, R.B., Juraimi, A.S. and Omar, D., 2010. Efficacy and cost-effectiveness of three broad-spectrum herbicides to control weeds in immature oil palm plantation. *Pertanika Journal of Tropical Agricultural Science*, 33(2), pp. 233-241.