Effect of selected treatments for glyphosate substitution in the chemical weed control of Persian lime (*Citrus latifolia* Tanaka)

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ABSTRACT

Objective: To determine the effectiveness of selected treatments for weed control compared to glyphosate in a Persian lime plantation.

Design/methodology/approach: The experiment was established in Ignacio de la Llave, Veracruz, in August 2024. A randomized complete block design with six treatments and four replications was used: glyphosate at 907.5 g ha^{-1}, diuron + paraquat at 1,600 + 500 g ha^{-1}, indaziflam + paraquat at 75 + 500 g ha^{-1}, indaziflam + glufosinate-ammonium at 75 + 300 g ha^{-1}, bromacil/diuron at 1,600/1,600 g ha^{-1}, and a control with no application. Weed control was evaluated at 10, 20, 30, 40, and 50 days after application (DAA).

Results: At 50 DAA, the most effective treatments for controlling *Ruellia ciliatiflora* Hook were indaziflam + paraquat at 75 + 500 g ha^{-1}, bromacil/diuron at 1,600/1,600 g ha^{-1}, and indaziflam + glufosinate-ammonium at 75 + 300 g ha^{-1}. *Paspalum dilatatum* Poir was effectively controlled with bromacil/diuron at 1,600/1,600 g ha^{-1} and diuron + paraquat at 1,600 + 500 g ha^{-1}. The best treatments for complete weed control were bromacil/diuron at 1,600/1,600 g ha^{-1} and indaziflam + paraquat at 75 + 500 g ha^{-1}.

Limitations on study/implications: The effectiveness of the evaluated treatments may vary depending on the weed species present.

Findings/conclusions: Bromacil/diuron at 1,600/1,600 g ha^{-1} and indaziflam + paraquat at 75 + 500 g ha^{-1} can be used as alternatives to glyphosate for weed control in Persian lime plantations.

Keywords: *Ruellia ciliatiflora*, *Paspalum dilatatum*, herbicides.

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INTRODUCTION

In Mexico, the state of Veracruz is the second-largest producer of lime, surpassed only by Michoacán. In Veracruz, Persian lime (*Citrus latifolia* Tanaka) is the main cultivated species, and its production area has increased significantly during the present century. While 17,495 ha were planted in 2000, the cultivated area increased more than threefold by 2024, reaching 52,930 ha (SIAP, 2025). This crop is an important source of direct and indirect employment and has a high benefit-cost ratio (Franco-Valderrama *et al.*, 2022).

Pests, diseases, and weeds are the main biotic constraints affecting Persian lime and citrus crops in general. In newly established plantations or during the early stages of crop development, inadequate and untimely weed control can reduce fruit yield by up to 33% due to competition for water, light, and nutrients (Martinelli *et al.*, 2017; Otieno, 2020). In mature plantations, weeds hinder agricultural operations and may serve as hosts for pests and diseases (Brown *et al.*, 2014; Onen *et al.*, 2018). For these reasons, efficient weed management is necessary, especially during critical stages of crop development and management or during periods of limited moisture availability (Bernardes *et al.*, 2021).

Although mechanical, chemical, and biological methods are available for weed control in citrus crops (Mia *et al.*, 2020; Matilde-Hernández *et al.*, 2024), the application of non-selective post-emergence herbicides, mainly glyphosate, is deeply rooted in Veracruz. Glyphosate can control annual and perennial weeds without leaving soil residues (Alcántara-de la Cruz *et al.*, 2021). However, because glyphosate does not prevent the emergence of new weed seedlings, it is generally applied three to four times per production cycle, depending on climatic conditions. Its continuous use for more than 15 years in citrus plantations in the municipalities of Cuitláhuac and Martínez de la Torre, Veracruz, resulted in the evolution of glyphosate-resistant biotypes of sprangletop grass [*Leptochloa virgata* (L.) P. Beauv.] (Pérez-López *et al.*, 2014). Currently, a total of seven weed species resistant to glyphosate have been reported in citrus orchards in Mexico (Heap, 2025).

In addition to the problems associated with the presence of herbicide-resistant weed biotypes, in 2015 the International Agency for Research on Cancer classified glyphosate as probably carcinogenic to humans (IARC, 2017). However, based on independent evaluations conducted by the United States Environmental Protection Agency, it was concluded that when glyphosate is used according to label instructions, it does not pose risks to human health and is not likely to cause cancer in humans (EPA, 2025). Consequently, substantial discrepancies still exist among scientists regarding the magnitude and significance of this issue (Tarazona *et al.*, 2017; Van Bruggen *et al.*, 2018).

In 2020, the Federal Government of Mexico published a decree in the Official Gazette of the Federation aimed at "gradually substituting the use, acquisition, distribution, promotion, and importation of the chemical substance known as glyphosate and the agrochemicals containing it as an active ingredient, with sustainable and culturally appropriate alternatives that maintain production while ensuring safety for human health, the country's biocultural diversity, and the environment" (SEGOB, 2020).

In the search for chemical, physical, and organic alternatives to replace this herbicide in different crops and production systems, from 2021 to 2024 the Federal Government of Mexico, through SENASICA and INIFAP, funded the research and validation project entitled "Alternatives to the Use of Glyphosate for Weed Control in Mexico," which consisted of 24 activities or subprojects. Activity 12, "Control Alternatives to Replace Glyphosate in Citrus Plantations in the State of Veracruz," focused on identifying chemical control alternatives for Persian lime and orange crops.

In Persian lime cultivation, four experiments were established from 2021 to 2023 in the municipalities of Tlalixcoyan and Medellín, Veracruz, where a total of 19 treatments were evaluated, including both chemical herbicides and some natural products that, in uncultivated fields, had shown weed control comparable to glyphosate (Esqueda-Esquivel *et al.*, 2025). From these treatments, the four most effective were selected. Therefore, the objective of this study was to determine the effectiveness of the selected treatments for weed control compared with glyphosate in a Persian lime plantation at an early stage of development.

MATERIALS AND METHODS

On August 2, 2024, an experiment was established in a Persian lime plantation located in the community of Barrio de los Evodios, municipality of Ignacio de la Llave, Veracruz (18° 42' 49.906" N, 95° 58' 29.241" W, at 8 m above sea level). Trees were planted at a spacing of 5 m between rows and 5 m between trees within the row. The plantation was six months old, and the trees were between 1 and 1.5 m in height. A randomized complete block design with six treatments and four replications was used.

The following treatments were evaluated: 1. Glyphosate at 907.5 g ha^{-1} (regional check), 2. Diuron + paraquat at 1,600 + 500 g ha^{-1}, 3. Indaziflam + paraquat at 75 + 500 g ha^{-1}, 4. Indaziflam + glufosinate ammonium at 75 + 300 g ha^{-1}, 5. Bromacil/diuron at 1,600/1,600 g ha^{-1}, and an untreated control. The "+" sign between two herbicides indicates a tank mixture, whereas the "/" sign indicates a commercially formulated mixture. An adjuvant, ADP (alkyl phenol), was added to treatments 1 through 5 at a rate of 2.5 mL L^{-1} of water used.

The experimental units were located between two tree rows and measured 4 m in width and 10 m in length. A 0.5 m strip was left on each side and used as a weedy lateral control during weed control evaluations. Herbicides were applied using a Honda WJR2525T® motorized backpack sprayer equipped with a boom containing four 8003 flat-fan nozzles, delivering 291 L of spray solution per hectare. Applications were directed toward the weeds, which showed vigorous growth due to favorable soil moisture conditions.

Before treatment application, weed population density by species was determined using 1 m × 1 m quadrats randomly placed within the four untreated control plots, and plant height was measured in five plants of each species. At 10, 20, 30, 40, and 50 DAA, visual evaluations were conducted for weed control by dominant species, overall weed control, and toxicity to Persian lime. In both cases, a percentage scale (0-100%) was used. For weed control, 0 indicated that the treatments had no effect on the weeds, whereas 100 indicated complete weed destruction. For toxicity to Persian lime trees, 0 indicated that the treatments caused no damage to the crop, whereas 100 indicated complete plant death (Singh *et al.*, 2012). Analyses of variance were performed using arcsine-transformed data, as recommended by Dey and Pandit (2020), and Tukey's test ($p \leq 0.05$) was used for mean separation. For clarity, the following section presents the original weed control data, together with the significance groupings obtained from the mean comparisons of the transformed data.

RESULTS AND DISCUSSION

Three weed species belonging to three botanical families were identified in the experimental field. A weed population density of 950,000 plants ha^{-1} was recorded, with *Ruellia ciliatiflora* Hook and *Paspalum dilatatum* Poir. identified as the dominant species. Together, these species accounted for 98.15% of the total weed density present in the experimental field (Table 1).

At 10 DAA, indaziflam + paraquat at 75 + 500 g ha^{-1} provided slightly more than 99% control of *R. ciliatiflora*, which was statistically superior to the remaining treatments, whose control levels ranged from 75 to 85%, with no significant differences among them. This treatment also showed the highest levels of control of *P. dilatatum*, together with diuron + paraquat at 1,600 + 500 g ha^{-1} and bromacil/diuron at 1,600/1,600 g ha^{-1}. Meanwhile, the control levels obtained with glyphosate at 907.5 g ha^{-1} and indaziflam + glufosinate ammonium at 75 + 300 g ha^{-1} ranged from 70 to 75%, and were statistically similar. For overall weed control, indaziflam + paraquat at 75 + 500 g ha^{-1} achieved 95% control, which was statistically similar to the 87.5% effectiveness obtained with diuron + paraquat at 1,600 + 500 g ha^{-1}. Glyphosate at 907.5 g ha^{-1} provided only slightly more than 70% control, similar to that obtained with bromacil/diuron at 1,600/1,600 g ha^{-1} and indaziflam + glufosinate ammonium at 75 + 300 g ha^{-1} (Table 2). During the study, none of the treatments caused toxicity to Persian lime trees (data not shown).

At 20 DAA, indaziflam + paraquat at 75 + 500 g ha^{-1} maintained almost complete control of *R. ciliatiflora*, which was significantly superior to the remaining treatments, although indaziflam + glufosinate ammonium at 75 + 300 g ha^{-1} and bromacil/diuron

Table 1. Scientific name, botanical family, population density, and average height of weed species at the experimental site. Barrio de los Evodios, municipality of Ignacio de la Llave, Veracruz, 2024.

Scientific name	Botanical familiy	Density (plants ha^{-1})	Average height (cm)
Ruellia ciliatiflora Hook	Acanthaceae	602,500	9.10
Paspalum dilatatum Poir	Poaceae	330,000	17.40
Cyperus eragrostis Lam.	Cyperaceae	17,500	17.43
Total		950,000	

Table 2. Effect of treatments on weed control by species and overall weed control (%) at 10 DAA.

Treatment (g ha^{-1})	*R. ciliatiflora*	*P. dilatatum*	Total
Gly (907.5)	76.25 b	73.75 bc	72.50 bc
Diu + Par (1,600 + 500)	83.75 b	98.00 a	87.50 ab
Ind + Par (75 + 500)	99.25 a	91.25 a	95.00 a
Ind + Glu (75 + 300)	82.50 b	70.00 c	70.00 c
Bro/Diu (1,600/1,600)	80.00 b	90.00 ab	72.50 bc
Control without application	0.00 c	0.00 d	0.00 d

Gly=Glyphosate, Diu=Diuron, Par=Paraquat, Ind=Indaziflam, Glu=Glufosinate ammonium, Bro=Bromacil. Letters to the right of the control values indicate Tukey's test ($p \leq 0.05$). Values followed by the same letter are not statistically different. Comparisons were made among treatments for each variable.

at 1,600/1,600 g ha^{-1} provided control levels of 90 and 97%, respectively. With glyphosate at 907.5 g ha^{-1} and diuron + paraquat at 1,600 + 500 g ha^{-1}, control was around 85%. Control of *P. dilatatum* ranged from 90 to 99% with the same treatments identified at 10 DAA, whereas with glyphosate at 907.5 g ha^{-1} and indaziflam + glufosinate ammonium at 75 + 300 g ha^{-1}, control was lower than 80 and 70%, respectively. For the overall weed population, indaziflam + paraquat at 75 + 500 g ha^{-1}, diuron + paraquat at 1,600 + 500 g ha^{-1}, and, for the first time, bromacil/diuron at 1,600/1,600 g ha^{-1} were the treatments with the highest and statistically similar levels of control. Glyphosate at 907.5 g ha^{-1} and indaziflam + glufosinate ammonium at 75 + 300 g ha^{-1} provided control levels ranging from 70 to 75% (Table 3).

At 30 DAA, indaziflam + paraquat at 75 + 500 g ha^{-1} still maintained almost complete control of *R. ciliatiflora*, and was statistically superior to the remaining treatments, although bromacil/diuron at 1,600/1,600 g ha^{-1} and indaziflam + glufosinate ammonium at 75 + 300 g ha^{-1} achieved control levels greater than 90%. Control of this species with glyphosate at 907.5 g ha^{-1} was close to 85%, whereas with diuron + paraquat at 1,600 + 500 g ha^{-1} it was lower than 80%. For *P. dilatatum*, both diuron + paraquat at 1,600 + 500 g ha^{-1} and bromacil/diuron at 1,600/1,600 g ha^{-1} showed 99% control, and were statistically superior to the remaining treatments. Indaziflam + paraquat at 75 + 500 g ha^{-1} provided control close to 90%, whereas control with glyphosate at 907.5 g ha^{-1} and indaziflam + glufosinate ammonium at 75 + 300 g ha^{-1} was poor. For the overall weed population, indaziflam + paraquat at 75 + 500 g ha^{-1} and bromacil/diuron at 1,600/1,600 g ha^{-1} achieved control levels greater than 90%, and were statistically superior to the remaining treatments. Diuron + paraquat at 1,600 + 500 g ha^{-1} provided control close to 85%, whereas glyphosate at 907.5 g ha^{-1} achieved slightly more than 70% control, and indaziflam + glufosinate ammonium at 75 + 300 g ha^{-1} only 65% control (Table 4).

At 40 DAA, indaziflam + paraquat at 75 + 500 g ha^{-1}, bromacil/diuron at 1,600/1,600 g ha^{-1}, and indaziflam + glufosinate ammonium at 75 + 300 g ha^{-1} provided control of *R. ciliatiflora* ranging from 90 to 100%, and were statistically similar to each other and superior to the remaining treatments. Control with glyphosate at 907.5 g ha^{-1} was slightly greater than 70%, significantly exceeding the approximately 50% control provided by diuron + paraquat at 1,600 + 500 g ha^{-1}. For *P. dilatatum*, only bromacil/diuron at 1,600/1,600 g

Table 3. Effect of treatments on weed control by species and overall weed control (%) at 20 DAA.

Treatment (g ha^{-1})	*R. ciliatiflora*	*P. dilatatum*	Total
Gly (907.5)	84.25 c	76.25 b	74.50 bc
Diu + Par (1,600 + 500)	85.00 c	99.00 a	87.50 ab
Ind + Par (75 + 500)	99.25 a	91.25 a	95.00 a
Ind + Glu (75 + 300)	90.00 bc	66.25 b	71.25 c
Bro/Diu (1,600/1,600)	97.00 b	98.75 a	95.50 a
Control without application	0.00 d	0.00 c	0.00 d

Gly=Glyphosate, Diu=Diuron, Par=Paraquat, Ind=Indaziflam, Glu=Glufosinate ammonium, Bro=Bromacil. Letters to the right of the control values indicate Tukey's test ($p \leq 0.05$). Values followed by the same letter are not statistically different. Comparisons were made among treatments for each variable.

Table 4. Effect of treatments on weed control by species and overall weed control (%) at 30 DAA.

Treatment (g ha^{-1})	*R. ciliatiflora*	*P. dilatatum*	Total
Gly (907.5)	83.75 cd	65.00 c	72.50 bc
Diu + Par (1,600 + 500)	77.50 d	99.00 a	83.75 b
Ind + Par (75 + 500)	99.25 a	89.75 b	93.00 a
Ind + Glu (75 + 300)	91.75 bc	57.50 c	65.00 c
Bro/Diu (1,600/1,600)	95.50 b	99.00 a	96.00 a
Control without application	0.00 e	0.00 d	0.00 d

Gly=Glyphosate, Diu=Diuron, Par=Paraquat, Ind=Indaziflam, Glu=Glufosinate ammonium, Bro=Bromacil. Letters to the right of the control values indicate Tukey's test ($p \leq 0.05$). Values followed by the same letter are not statistically different. Comparisons were made among treatments for each variable.

ha^{-1} and diuron + paraquat at 1,600 + 500 g ha^{-1} maintained control levels greater than 95%, and were statistically superior to the remaining treatments, whereas control with indaziflam + paraquat at 75 + 500 g ha^{-1} was slightly greater than 85%, and significantly superior to glyphosate at 907.5 g ha^{-1} and indaziflam + glufosinate ammonium at 75 + 300 g ha^{-1}, which showed the lowest levels of control. Overall weed control with bromacil/diuron at 1,600/1,600 g ha^{-1} was 96%, whereas indaziflam + paraquat at 75 + 500 g ha^{-1} provided control close to 90%, although both treatments were statistically similar. In the remaining chemical treatments, control ranged from 55 to 65% (Table 5).

Finally, at 50 DAA, indaziflam + paraquat at 75 + 500 g ha^{-1}, bromacil/diuron at 1,600/1,600 g ha^{-1}, and indaziflam + glufosinate ammonium at 75 + 300 g ha^{-1} maintained control of *R. ciliatiflora* ranging from 90 to 100%, and were statistically similar and superior to glyphosate at 907.5 g ha^{-1} and diuron + paraquat at 1,600 + 500 g ha^{-1}, which only outperformed the untreated control. At this evaluation time, bromacil/diuron at 1,600/1,600 g ha^{-1} and diuron + paraquat at 1,600 + 500 g ha^{-1} still maintained control levels greater than 90% of *P. dilatatum*. With indaziflam + paraquat at 75 + 500 g ha^{-1}, control was close to 85%, and significantly superior to that obtained with indaziflam + glufosinate ammonium at 75 + 300 g ha^{-1} and glyphosate at 907.5 g ha^{-1}, which were the chemical treatments with the lowest levels of control. Regarding the overall weed population, control with bromacil/diuron at 1,600/1,600 g ha^{-1} was 95.5%, whereas with

Table 5. Effect of treatments on weed control by species and overall weed control (%) at 40 DAA.

Treatment (g ha^{-1})	*R. ciliatiflora*	*P. dilatatum*	Total
Gly (907.5)	71.25 b	52.50 c	63.75 b
Diu + Par (1,600 + 500)	52.50 c	98.50 a	63.75 b
Ind + Par (75 + 500)	99.25 a	86.00 b	87.75 a
Ind + Glu (75 + 300)	91.25 a	46.25 c	55.00 b
Bro/Diu (1,600/1,600)	94.25 a	98.75 a	96.00 a
Control without application	0.00 d	0.00 d	0.00 c

Gly=Glyphosate, Diu=Diuron, Par=Paraquat, Ind=Indaziflam, Glu=Glufosinate ammonium, Bro=Bromacil. Letters to the right of the control values indicate Tukey's test ($p \leq 0.05$). Values followed by the same letter are not statistically different. Comparisons were made among treatments for each variable.

indaziflam + paraquat at 75 + 500 g ha^{-1} it was 85.5%, although both were statistically similar. With indaziflam + glufosinate ammonium at 75 + 300 g ha^{-1} and glyphosate at 907.5 g ha^{-1}, control was around 50% (Table 6).

Although the ban on glyphosate use published in the Official Gazette of the Federation in 2020 was based mainly on risks to human health, most regulatory agencies worldwide have indicated that the proper use of glyphosate does not pose risks to human health or the environment (Alcántara-de la Cruz *et al.*, 2021). Likewise, studies have shown that the risk of glyphosate (Hunter and Blecker, 2019) and other pesticides being inhaled or coming into contact with the skin or eyes of applicators is significantly reduced when protective clothing is used (Yarpuz-Bozdogan, 2018; Naksata *et al.*, 2020). It is also known that environmental contamination problems occur mainly when doses higher than those recommended and multiple applications during the crop cycle are used (Yamada *et al.*, 2009; Hanke *et al.*, 2010). Therefore, regulating glyphosate application in terms of dosage, number of applications, and use of protective clothing would be more appropriate than banning it.

The increasing occurrence of glyphosate-resistant weed biotypes in different crops and countries is a matter of concern. As of December 2025, 388 glyphosate-resistant biotypes belonging to 61 weed species have been reported in 30 countries (Heap, 2025), and it is considered that additional cases still remain undocumented. For this reason, it is very important to have alternative chemical control options, such as those identified in this experiment, that can be used in situations where glyphosate-resistant weed biotypes are already present, or where this herbicide has been applied for many years and there is a high risk of their appearance. Rotation with herbicides having different modes of action reduces selection pressure on individual sites of action and eliminates resistant biotypes already present or delays their appearance (Beckie, 2006; Norsworthy *et al.*, 2012).

In this experiment, it was determined that the best alternatives to glyphosate for overall weed control were bromacil/diuron at 1,600 + 1,600 g ha^{-1} and indaziflam + paraquat at 75 + 500 g ha^{-1}. The first treatment is applied in preemergence or early postemergence and can maintain efficient control of grass and broadleaf weeds for more than 90 days without causing toxicity to citrus crops (Singh and Tucker, 1988). In two experiments conducted in Persian lime orchards in the state of Puebla, Alcántara-de la

Table 6. Effect of treatments on weed control by species and overall weed control (%) at 50 DAA.

Treatment (g ha^{-1})	*R. ciliatiflora*	*P. dilatatum*	Total
Gly (907.5)	61.25 b	37.50 c	48.75 b
Diu + Par (1,600 + 500)	43.75 b	96.00 ab	53.75 b
Ind + Par (75 + 500)	99.25 a	83.50 b	85.50 a
Ind + Glu (75 + 300)	90.75 a	40.00 c	50.00 b
Bro/Diu (1,600/1,600)	93.75 a	98.00 a	95.50 a
Control without application	0.00 c	0.00 d	0.00 c

Gly=Glyphosate, Diu=Diuron, Par=Paraquat, Ind=Indaziflam, Glu=Glufosinate ammonium, Bro=Bromacil. Letters to the right of the control values indicate Tukey's test ($p \leq 0.05$). Values followed by the same letter are not statistically different. Comparisons were made among treatments for each variable.

Cruz *et al.* (2019) determined that at 75 DAA, control of hairy beggarticks (*Bidens pilosa* L.) and *L. virgata* with glyphosate at 1,080 g ha^{-1} was around 40%, whereas when the bromacil + diuron mixture at 1,200 + 1,200 g ha^{-1} was added, control increased to nearly 90%. This indicates that this mixture may be useful for controlling weed species that show resistance to glyphosate. However, it should be applied only once during the crop cycle because bromacil has very high mobility in the soil and, under conditions of high rainfall, may leach, reducing the weed control period and increasing the risk of groundwater contamination (Gomez de Barreda *et al.*, 1993).

Regarding the indaziflam + paraquat treatment, the first herbicide is applied only in preemergence, and its effectiveness may vary according to the dose, soil texture, and weed species present (Amim *et al.*, 2014). Esqueda-Esquivel (2012) found that at a dose of 50 g ha^{-1}, control of *L. virgata* at 75 DAA ranged from 90 to 95%, whereas the control provided by diuron at 1,600 g ha^{-1} was only around 40%. However, when comparing the effectiveness of indaziflam alone, indaziflam + rimsulfuron, and rimsulfuron alone, Faber *et al.* (2016) determined that six months after application, weed control was significantly greater when the mixture of both herbicides was applied compared with their individual application. In Persian lime plantations developed exclusively under rainfed conditions, it is almost impossible to apply indaziflam in preemergence because weeds are continuously present. Under these conditions, the indaziflam + paraquat mixture could be very useful, since paraquat would control emerged weeds, whereas indaziflam would prevent the emergence of new weed seedlings for an extended period of time. In Mexican lime cultivation in the state of Colima, Orozco-Santos and García-Mariscal (2023) determined that this mixture, at doses of 100 and 400 g ha^{-1}, provided efficient weed control for six months. In addition, herbicide costs were reduced by 45% compared with the regional standard treatment, consisting of six glyphosate applications. Lozano-Contreras and Avilés-Baeza (2025) indicated that the same treatment, applied at doses of 200 + 800 g ha^{-1} in orange cultivation in Yucatán, in addition to providing efficient weed control up to 75 DAA, favored the vegetative development of the trees by increasing canopy diameter, stem thickening, and shoot production. This represents an additional advantage over glyphosate application, since in Brazil it has been demonstrated that the repeated use of this herbicide can significantly reduce tree vigor and fruit production in citrus crops, greatly decreasing their financial viability (Martinelli *et al.*, 2022).

Although in this experiment the mixtures of diuron + paraquat at 1,600 + 500 g ha^{-1} and indaziflam + glufosinate ammonium at 75 + 300 g ha^{-1} did not show the same effectiveness in overall weed control or duration of control as the two treatments previously mentioned, with other weed species they could also represent alternatives for glyphosate replacement. Therefore, it is recommended to carry out an exploratory application of the four treatments in a small area of the orchard before applying any of them to the entire plantation area.

It is very important to indicate that, in order to avoid toxicity to citrus crops with any herbicide treatment, contact of the spray solution with the foliage or trunk of the trees should be avoided, especially in newly established plantations or during early stages of development (Kanissery *et al.*, 2021).

CONCLUSIONS

The formulated mixture of bromacil/diuron at a dose of 1,600/1,600 g ha^{-1} and the tank mixture of indaziflam + paraquat at a dose of 75 + 500 g ha^{-1} are efficient alternatives to replace glyphosate for weed control in Persian lime cultivation.

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