



# Herbicides and Plastic Covers for Weed Control in Orange Crops *Citrus sinensis* (L.) Osbeck

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**How to cite this paper:** Lozano-Contreras, M.G. and Avilés-Baeza, W.I. (2025) Herbicides and Plastic Covers for Weed Control in Orange Crops *Citrus sinensis* (L.) Osbeck. *Open Access Library Journal*, 12: e14023.

<https://doi.org/10.4236/oalib.1114023>

**Received:** July 26, 2025

**Accepted:** September 21, 2025

**Published:** September 24, 2025

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## Abstract

Weeds represent one of the main constraints in citrus production, as they compete for water, light, and nutrients, in addition to interfering with agricultural work. In Yucatán, Mexico, sweet orange (*Citrus sinensis*) cultivation is of great economic and social importance, but it can suffer losses of up to 40% due to weed proliferation. Given the progressive reduction in the use of glyphosate, sustainable and effective alternatives are needed. The objective of this study was to evaluate the effect of different combinations of herbicides and plastic covers on weed control in a young orange plantation. The experiment was conducted during the fall-winter cycle of 2023 in Muna, Yucatán, in a five-month-old plantation. Eight treatments were evaluated: combinations of preemergent and postemergent herbicides (ammonium glufosinate, paraquat, halosulfuronmethyl, indaziflam, glyphosate) and two plastic covers (silver/black plastic and black mesh). A randomized complete block design with four replicates was used. Weed coverage, phytotoxicity symptoms, and crop morphological variables were recorded up to 90 days after application. The plastic cover treatments achieved total weed control (0.0%) up to 75 days, followed by Paraquat + Halosulfuron methyl (0.4% - 7.9%). No symptoms of phytotoxicity were observed in the plants. Although there were no statistical differences in growth, the treatments. Although there were no statistical differences in growth, the most effective weed control treatments showed positive trends in vegetative development. It is concluded that plastic mulch and specific herbicide mixtures offer effective and safe alternatives for weed control in citrus under tropical conditions, with potentially beneficial effects on crop development.

## Subject Areas

Agricultural Engineering

## Keywords

Weed Control, Phytotoxicity, Herbicides, Padded

## 1. Introduction

Different studies have documented that weeds represent a limiting factor in citrus production, mainly due to the competition with the crop for essential resources such as nutrients, water, light and space. In addition, weeds significantly interfere with agronomic management tasks, including pruning, agrochemical spraying and harvesting, which negatively impact the efficiency of the production system [1]-[3].

An illustrative example is reported by several authors in this crop. In young plantations, the presence of weeds during the dry season represents a critical problem due to their intense competition activity. In contrast, in the productive stage, weeds proliferation has been associated with an increase in the fall of immature fruits, which reduces both yield and the number of fruits per tree, causing losses estimated between 30 and 40% of the harvest [2] [3].

In the state of Yucatan, Mexico, citrus activity has a great food, social, cultural and economic importance [4]. Currently, approximately 14,570 hectares of sweet orange are cultivated in the state, with a production value of over 857 million Mexican pesos [5]. These important activities can be affected by various factors, including weeds, especially during the critical period of competition, which corresponds to the minimum time the crop must be kept free of weeds to avoid significant losses [6] [7].

Local farmers commonly combine manual weeding in the crop rows and herbicides between rows [8]. Over time, various herbicides have been introduced with good effectiveness in pre- and early post-emergence sprayings, especially in the early phenological stages of weeds. However, the intensive use of chemical herbicides, while effective in controlling certain species, also leads to significant negative effects, such as the evolution of resistant weeds, phytotoxic residues in crops and environmental pollution [9]. Such is the particular case of the herbicide glyphosate, in relation to which Mexico has implemented agroecological transition policies with the main objective of reducing or eventually eliminating the use of glyphosate [10]. According to a Presidential Decree (2020), its substitution should be using sustainable and culturally appropriate alternatives to maintain crop production and human health safety, as well as being friendly with the biocultural diversity of the country and the environment [11]. In this context, alternative strategies are explored to reduce competition between weeds and an orange crop, in order to improve the crop development and productivity. The main objective of this study was to assess the efficacy of different mixtures of synthetic herbicides and plastic covers on weed control to significantly reduce competition during the development stage of the orange crop (*Citrus sinensis*).

## 2. Materials

### 2.1. Location

The research was carried out in the Agricultural Unit “José López Portillo Pozo 3”, in the municipality of Muna, Yucatan, Mexico; located at the coordinates

20°24'52" north latitude and 89°48'30" west longitude in a soil classified as Ak' al che' in Mayan terms and Luvisol in the World Soil Reference Base (WRB) [12].

## 2.2. Identification of Weed Species

Weed species were identified in the field a week before treatment establishment, using 12 squares of 1.0 m<sup>2</sup> (1.0 × 1.0 m) to record the data of each species. The frequency of appearance, abundance and dominance of each species were recorded and the Importance Value Index (IVI) of each species was calculated adapting the methodology described by Gámez López *et al.* (2011) [13]. The Importance Value Index (IVI) was developed by Curtis & McIntosh (1951) [14]. It is a synthetic structural index, developed mainly to rank the dominance of each species in mixed stands and was calculated as follows: IVI = Relative dominance + Relative density + Relative frequency [15] [16]. According to Campo and Duval (2014) [17], these three parameters are calculated as follows:

$$\text{Relative dominance} = \frac{\text{Dominance of each species}}{\text{Dominance of all species}} \times 100$$

$$\text{Relative Density} = \frac{\text{Number of individuals of each species}}{\text{Total Number of individuals}} \times 100$$

$$\text{Relative frequency} = \frac{\text{Frequency of each species}}{\text{Frequency of all species}} \times 100$$

## 3. Methods

### 3.1. Treatments and Crop Management

The study was carried out from July to September of 2023 (autumn-winter season) in a five-month-old sweet orange plantation cv Valencia Late (grafted on sour orange), 86 cm height, watered with a drip irrigation system. In the second week of July, the contact herbicide Paraquat (200 g of active ingredient L<sup>-1</sup>) was sprayed using a dose of 10 mL of commercial material per liter of water, to eliminate the first weeds that emerged. Once the weeds began to recover, two treatments with plastic covers were installed from July 24 to 26, and herbicide treatments were applied on July 27. Eight treatments were evaluated (Plastic covers and herbicides); in the first five treatments, pre-emergent herbicides (Glufosinate ammonium and Paraquat), mixed with the contact herbicides Halosulfuron methyl or Indaziflam, were sprayed when weeds re-started growing after Paraquat spraying. A second spray was made on treatments T1 (Aug/29), T2, T3, T6 and T7 (6/Sept). T1 was the Farmer's Control, based on Glyphosate and T8 was No Weeding Control (**Table 1**). Doses used were determined based on the herbicide manufacturer's and INIFAP's suggestions; legal regulations for Mexico and USA were also considered. Crop management was carried out according to recommendations of Avilés *et al.* (2010) [18] for Yucatan, Mexico environmental conditions.

### 3.2. Experimental Design and Statistical Analysis

The experiment was carried out using a randomized complete block design with four replications. The experimental units were 144.0 m<sup>2</sup> (18 m long and 8 m wide). Plants and rows were 6.0 and 6.0 m apart and the experimental unit included six plants (278 plants/Ha) and 24 plants per treatment.

Data were analyzed using the Analysis of Variance (ANOVA), Mean Comparison Test by Tukey's method ( $p \leq 0.05$ ), through the Statgraphics Centurion program, version 16.1.2.0 [19].

### 3.3. Total Weed Coverage (%)

The percentage of coverage was measured visually, adapting the methodology described by Rodríguez *et al.* (2008) [20] and Gámez López *et al.* (2011) [13] for weed populations. Eight quadrants of 1.0 m × 1.0 m (1.0 m<sup>2</sup>) were used per treatment (two quadrants per replication) at 15, 30, 45, 60 and 75 days after herbicide spraying (das). Subsequently, the data were transformed to arcsine root of x for statistical analysis (ANOVA).

**Table 1.** Treatments for weeds control in a sweet orange crop (Spring-Summer period 2023-24).

Treatment	Herbicide	g of active ingredient (a-i) Kg <sup>-1</sup> or L <sup>-1</sup>	Commercial Dose (L or Kg-ha <sup>-1</sup> )	Dose of a-i (Kg a-i Kg <sup>-1</sup> or L <sup>-1</sup> )	*Chemical Group (HRAC)	TC
1	<i>Glyphosate</i>	360	4.0	1.92	Glycines	III
2	<i>Glufosinate ammonium + Halosulfuron methyl</i>	143 + 750	4.0 + 0.2	0.572 + 0.15	Phosphinic acids Halosulfuron	III + IV
3	<i>Paraquat + Halosulfuron methyl</i>	200 + 750	4.0 + 0.2	0.8 + 0.15	Pyridiniums Halosulfuron	II + IV
4	<i>Plastic mulch (Silver/black plastic film Caliber 90)</i>	---	---	---	---	---
5	<i>Ground cover black</i>	---	---	---	---	---
6	<i>Paraquat + Indaziflam</i>	200 + 500	4.0 + 0.4	0.8 + 0.2	Pyridiniums Alkylazines	II + III
7	<i>Glufosinate ammonium + Indaziflam</i>	143 + 500	4.0 + 0.4	0.572 + 0.2	Phosphinic acids Alkylazines	III + III
8	<i>Control (No weeding)</i>	---	---	---	---	---

\*(HRAC)= Herbicides Resistance Action Committee 2020; TC = Toxicological Category. Volume of water used: 400 L ha<sup>-1</sup> (Tee Jet 8002 nozzles).

### 3.4. Herbicides' Phytotoxicity

Phytotoxicity, percentage of mortality and symptomatology of herbicide damage on the crop were recorded using the method proposed by the European Weed Research Society (EWRS) cited by Pérez *et al.* (2014) [21] (Table 2) at 15, 30, 45, 60 and 75 das.

**Table 2.** Reference values suggested by the European Weed Research Society (EWRS) for weeds control and crop phytotoxicity.

Grades	Effect on the weeds	Effect on the crop
2	Very high control	Very light symptoms
3	Good control	Light symptoms
4	Sufficient control	Yields are not affected
Acceptability limits		
5	Medium control	Medium damage
6	Regular	High damage
7	Poor	Very high damage
8	Very poor	Severe damage
9	No effect on weeds	Total damage until death
Grades	Weed control (%)	Phytotoxicity on crop
1	99.0 - 100.0	0.0 - 1.0
2	96.5 - 99.0	1.0 - 3.5
3	93.0 - 96.5	3.5 - 7.0
4	87.5 - 93.0	7.0 - 12.5
5	80.0 - 87.5	12.5 - 20.0
6	70.0 - 80.0	20.0 - 30.0
7	50.0 - 70.0	30.0 - 50.0
8	1.0 - 50.0	50.0 - 99.0
9	0.0 - 1.0	99.0 - 100.0

Source: Urzúa (2001), Cited by Pérez *et al.* 2014.

### 3.5. Growth Variables

Four morphological variables were recorded in the crop: crown and rootstock diameter, graft diameter and number of shoots. Recordings were carried out before and 90 days after the treatments. Crown diameter was measured in the north-south and east-west orientations, considering eight plants per treatment (two per replication). For these measurements the increase in crown diameter was estimated [22]. The diameter of the rootstock and graft was recorded at 10 cm below and above the grafting point, respectively, using a steel vernier (Truper brand) and the increase of both diameters was calculated [22]. The number of shoots was quantified on the same eight plants, counting the total number of shoots emitted at 90 days after spraying (das) and calculating the increase during the period.

## 4. Results

### 4.1. Identification of Weeds

Eight dominant weed species were detected: Nutsedge (*Cyperus rotundus*), *Chamaecrista flexuosa* (Common name unknown), Erect spiderling (*Boerhavia*

*erecta*), False mallow (*Malvastrum corchorifolium*), Parthenium (*Parthenium hysterophorus*), Johnson grass (*Sorghum halepense*), Widow's tears (*Commelina erecta*), Yuyo blanco (*Urochloa panicoides*). 50% of the weeds were narrow-leaf species (*Cyperus rotundus*, *Sorghum halepense*, *Commelina erecta* and *Urochloa panicoides*) and 50% broad-leaf species (*Boheravia erecta*, *Chamaecrista flexuosa*, *Malvastrum corchorifolium* and *Parthenium hysterophorus*). According to the Importance Value Index (IVI), the outstanding species were: *Cyperus rotundus* (Cyperaceae) and *Sorghum halepense* (Poaceae) with values of 191.3 and 40.3%, respectively (Figure 1).

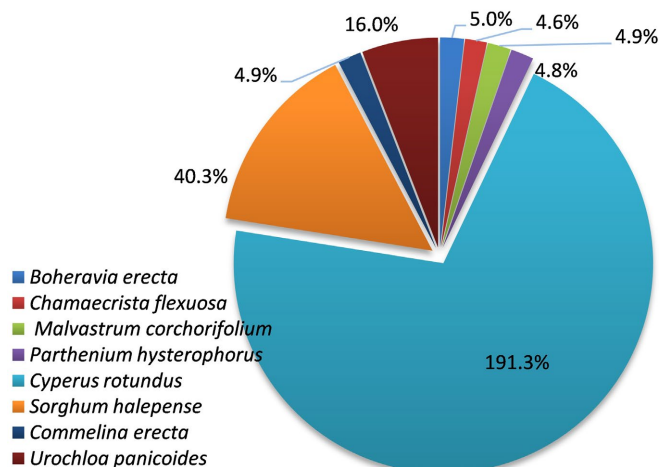


Figure 1. Relative Importance Values (RIVs) of weeds (%).

## 4.2. Total Coverage of Weeds (%)

Table 3. Weed coverage (%) behavior according to herbicide spraying and the use of plastic covers in a sweet orange crop.

N° of Treat	Treatments	Weed Coverage (%)				
		15 das	30 das	45 das	60 das	75 das
1	<i>Glyphosate</i>	14.3 bc	56.5 c	16.4 ab	32.8 b	13.4 b
2	<i>Glufosinate ammonium</i> + <i>Halosulfuron methyl</i>	9.3 abc	10.9 a	27.3 b	27.6 b	18.3 b
3	<i>Paraquat</i> + <i>Halosulfuron methyl</i>	0.4 ab	7.9 a	2.3 a	3.9 a	7.6 ab
4	<i>Plastic mulch (silver/black plastic film Caliber 90)</i>	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a
5	<i>Ground cover black</i>	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a
6	<i>Paraquat</i> + <i>Indaziflam</i>	13.1 abc	36.9 b	4.9 ab	19.4 b	32.4 c
7	<i>Glufosinate ammonium</i> + <i>Indaziflam</i>	16.1 c	44.7 bc	9.1 ab	23.9 b	39.5 c
8	<i>Control (No weeding)</i>	54.9 d	91.8 d	78.5 c	98.9 c	71.6 d

Note: Different letters mean significant statistical differences ( $p \leq 0.05$ , Tukey).

The Analysis of Variance (ANOVA) detected highly significant differences between treatments at 15, 30, 45, 60 and 75 days after spraying (das) (Table 3). It

was evident that both covers (Plastic mulch and Ground cover) controlled weeds through samplings from 15 to 75 das, showing the lowest levels of weed coverage (0.0% in both treatments). The only chemical treatment at similar statistic levels of weed coverage was Paraquat + Halosulfuron methyl, showing values from 0.4 to 7.9%. Other chemical treatments like Glufosinate ammonium + Halosulfuron methyl and Paraquat + Indaziflam only showed partial control of weeds in the first 30 days (Glufosinate ammonium, 9.3% and 10.9% of weed coverage) or at 15 and 45 das (Paraquat + Indaziflam, 13.1% and 4.9% of weed coverage). Glyphosate (Farmer's control) and Glufosinate ammonium + Indaziflam only showed an effective weed control at 45 das with coverage values of 16.4% (Glyphosate) and 9.1% (Glufosinate ammonium).

### 4.3. Phytotoxicity on the Crop

No phytotoxicity symptoms were observed in orange plants at 15, 30, 45, 60 and 75 days after spraying (das). Likewise, no physical damage was detected in the plastic cover treatments (Plastic mulch and Ground cover) during the sampling period.

### 4.4. Crop Growth Parameters

No significant statistical differences were found in the growth variables measured on the crop. However, data showed consistent trends that correlate with the levels of weed control observed in some treatments, which suggests that these trends could show significant differences in the near future.

**Table 4.** Increase in growth parameters of orange trees at 90 days after spraying.

Treatment (N°)	Herbicide	Crown diameter (cm)		Stem Diameter (mm)		N° of Shoots
		N-S <sup>ns</sup>	E-W	Rootstock <sup>ns</sup>	Graft <sup>ns</sup>	
1	<i>Glyphosate</i>	16.19	13.13	3.51	2.75	9.38
2	<i>Glufosinate ammonium + Halosulfuron methyl</i>	9.38	10.38	2.66	2.35	7.25
3	<i>Paraquat + Halosulfuron methyl</i>	12.94	12.38	2.56	2.65	5.25
4	<i>Plastic mulch (silver/black plastic film Caliber 90)</i>	25.10	24.00	3.31	3.45	14.00
5	<i>Ground cover black</i>	25.63	29.63	2.94	3.31	10.50
6	<i>Paraquat + Indaziflam</i>	27.00	25.56	3.45	2.93	11.63
7	<i>Glufosinate ammonium + Indaziflam</i>	22.19	22.00	2.43	2.23	10.88
8	<i>Control (No weeding)</i>	16.19	13.13	3.51	2.75	9.38

Note: <sup>ns</sup>Non-significant differences. N-S: North-South. E-W: East-West.

Plastic mulch, Ground cover and Paraquat + Indaziflam showed the highest values in all morphological variables measured, suggesting a positive impact on the vegetative development of the crop (**Table 4**). On the other hand, Glufosinate

ammonium + Indaziflam showed an outstanding performance on specific variables of vegetative development, particularly on crown diameter (north-south and east-west orientations), as well as the number of shoots emitted. This behavior is relevant because, despite presenting a lower level of weed control compared to other treatments, this combination favored crop growth.

## 5. Discussion

The results obtained confirm the significant impact of weed interference in citrus orchards, particularly in regions where water resources are limited. As pointed out by Martinelli *et al.* (2017) [23], yield losses associated with weed competition can reach up to 33%, which underlines the urgency of implementing more efficient management strategies. In young orchards, this competition becomes even more relevant, since the limited canopy cover and low root competition of citrus favor the development of aggressive weed species, as highlighted by Bernardes Soares *et al.* (2021) [3].

In this context, *Cyperus rotundus* emerged as the dominant species in the study area, registering the highest value of the Importance Value Index (IVI), with 191.3%. This high dominance aligns with that reported by Brosnan and DeFrank (2008) [24], who describe this species as one of the most problematic in tropical agricultural systems due to its high capacity for vegetative multiplication. It has been reported that, under favorable conditions, a single plant originating from a tuber can produce 100 or more tubers in just 100 days, allowing rapid infestation of the soil and prolonged persistence in the cropping system.

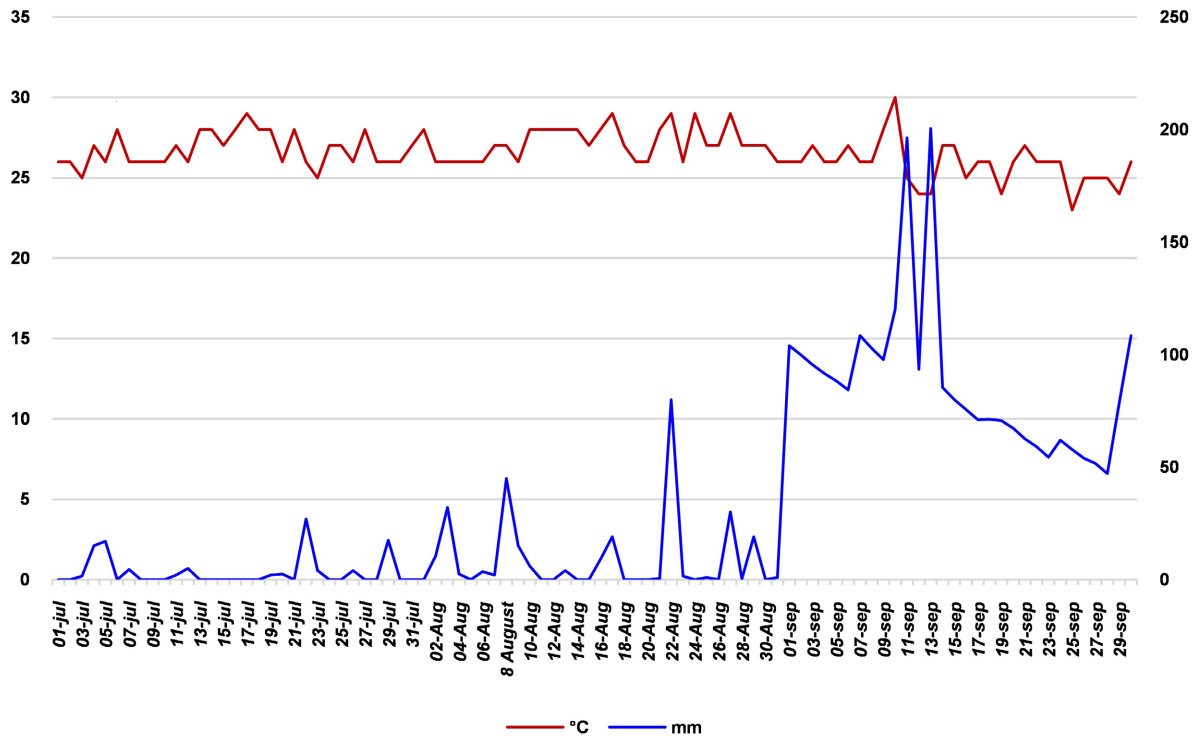
The presence of subway structures such as roots and rhizomes not only favors its clonal spread, but also makes its eradication difficult, especially when conventional tillage practices that fragment and redistribute these structures are used. In addition, the displacement of tubers by agricultural machinery contributes to the expansion of the weed within and between plots, which aggravates its control [25].

Treatments that included Halosulfuron methyl in their formulation (T2 and T3) showed greater efficacy in weed control. This result can be attributed to the physicochemical properties and mode of action of halosulfuron methyl (3-chloro-5-(4,6-dimethoxypyrimidin-2-ylcarbamoyl) sulfamoyl-1-methylpyrazole-4 carboxylate), a selective post-emergent application herbicide, effective mainly against broadleaf weeds and species of the genus *Cyperus*, such as *Cyperus rotundus* [26]. This compound acts by inhibiting the enzyme Acetolactate Synthase (ALS), which is essential in the synthesis of essential amino acids (valine, leucine and isoleucine) [27]. Its inhibition leads to rapid disruption of cell division, which arrests weed growth in both roots and shoots. In addition, halosulfuron-methyl has a high foliar and root uptake capacity and is efficiently translocated through the xylem and phloem, which explains its effectiveness in the systemic control of treated weeds [28] [29].

On the other hand, the mixture of Paraquat and Halosulfuron methyl, was the one that showed a higher efficacy and continuity in weed control during 75 days

compared to all herbicide-based treatments, this could be caused by the fact that paraquat (1, 1'-dimethyl-4,4'-bipyridine dichloride), is a non-selective broad-spectrum herbicide that acts by contact action, *i.e.*, it does not dislodge, but affects the green plant organs exposed on the surface [30]. Halosulfuron methyl, being a selective, post-emergent herbicide, has been successfully reported to control species of the genus *Cyperus*, in crops such as sugarcane, maize, sweet bell pepper, and husk tomato [31]-[34].

It was observed that the effectiveness of herbicide treatments was greater during the first 15 and 30 days after spraying (das), compared to later evaluations up to 75 dda. This indicates that the herbicides used do not exhibit a prolonged effect, which may require additional applications to maintain weed control throughout the crop cycle. The need for a new spraying would imply an increase in production costs, as well as a higher operational burden. However, the high efficacy observed during the first 30 days is particularly relevant, as it coincides with the beginning of rainy season and also initial stages of crop development in the year, a period in which weed competition can critically affect the crop growing and production (see **Figure 2**). Therefore, effective control in these early stages is essential to ensure a good crop start, even if the herbicide effect is not prolonged to later stages.



**Source:** Meteorological data from the Uxmal Experimental Station INIFAP.

**Figure 2.** Temperature and rainfall at the experimental site from July to September 2023.

Regardless of the effectiveness observed in weed control with the different treatments, it is noteworthy that the mixtures of two different herbicides provided more effective coverage compared to the exclusive application of glyphosate, which

showed limited control on weeds. This behavior has been reported by several authors, who mention that herbicide combination can be an effective measure to overcome deficiencies in the control of one or more weed species, as well as to face the growing problem of herbicide resistance [35]-[37].

On the other hand, plastic covers showed greater effectiveness in weed suppression during the entire evaluation period, positioning themselves as a sustainable and longer-lasting alternative to the exclusive use of herbicides. This effectiveness can be attributed to the physical and thermal properties of the mulch, particularly the black plastic, which acts as a barrier that prevents the passage of sunlight, thus blocking photosynthesis in weed seeds. According to Chuyma Tomaylla and Miranda Ruiz (2018) [38], mulching modifies soil microenvironmental conditions, affecting weed germination and growth due to the increase in temperature under the cover. In addition, mulching protects the soil from climatic factors such as wind and rain, preserving the soil structure and moisture generated by previous agricultural work, such as fallow and harrowing.

In addition to the effect on weed control, the use of mulch in citrus also favored increased plant growth. This positive effect has been documented in several crops. For example, Sangoquiza-Caiza *et al.* (2024) [39] reported that mulching significantly increased vegetative development in corn plants. Similarly, Velásquez *et al.* (1997) [40] observed that, in the cultivation of *Capsicum annuum* L. the use of plastic mulch significantly improved agronomic variables and allowed harvest to be brought forward by 21 days compared to treatments without mulch. For their part, Chuyma Tomaylla and Miranda Ruiz (2018) [38] demonstrated that the use of beds with polyethylene mulch in the production of *Solanum lycopersicum* L. increased yields by 40.35% compared to the control treatment without plastic mulch. These findings coincide with the results observed in the present study, which reinforces the potential of mulching as an effective agricultural practice to improve growth and yield in different crops.

Beyond their agronomic effectiveness, the choice of weed control methods must also consider their economic feasibility for growers. According to October 2024 prices (including materials and labor), the annual costs of herbicide treatments are estimated to range from \$3,930.00 (USD) for Glyphosate to \$10,522.00 (USD) for Glufosinate Ammonium + Halosulfuron Methyl. Plastic covers would cost \$6,717.00 for Silver/Black Mulch and \$4,972.00 for Black Ground Cover. These costs can be recovered by harvesting relatively low quantities of fruit, ranging from 0.65 ton (Glyphosate) to 1.75 ton (Glufosinate ammonium + Halosulfuron methyl) among herbicides and from 0.82 ton (Black ground cover) to 1.11 ton (Silver/black mulch), in the case of plastic covers.

## 6. Conclusions

The results obtained confirm that all treatments showed significant weed control compared to the control treatment (no weeding) in a *Citrus sinensis* plantation at the development stage.

Among the alternatives evaluated, the treatments with plastic mulch (silver/black, caliber 90), Ground cover (black) and herbicide mixtures of Paraquat + Halosulfuron methyl, Glufosinate ammonium + Halosulfuron methyl, and Paraquat + Indaziflam showed the best efficacy levels, prolonging weed control effect up to 75 das.

During the experimental period, no signs of phytotoxicity were detected in the sweet orange plants, nor were there any visible effects associated with the herbicide treatments or the plastic covers, indicating their agricultural compatibility with the crop under tropical conditions.

Additionally, the treatments with Plastic mulch (silver/black, caliber 90), Ground cover (black) and Paraquat + Indaziflam significantly favored the vegetative development of orange trees, reflected in greater crown diameter, stem thickness (rootstock and graft) and greater shoot emission up to 90 days of evaluation.

### Acknowledgements

We thank the National Institute of Forestry, Agricultural and Livestock Research (INIFAP) of Mexico for financing this work as part of the project called: *Alternatives to the use of Glyphosate for weed control in Mexico*. (Alternativas al uso del Glifosato para el control de Maleza en México)

### Conflicts of Interest

The authors declare no conflicts of interest.

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