Article

Effect of pre-emergent herbicides on weed control and onion development under fertigation conditions

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Abstract

The onion is slow growing, low in height and has small roots. For this reason, it has a disadvantage in the face of weeds, which, if not controlled, affect crop yield. The objective of the present work was to evaluate the effect of the combination of the pre-emergent herbicides Pendimethalin, Oxifluorfen, Oxadiazon, Acetoclor and Flumioxazin on the weed population and the crop yield. The experiment was established during the autumn-winter 2016-2017 cycle on a farm in Culiacán, Sinaloa (Mexico). There were 16 treatments, including the control without herbicide application. The experimental design was randomized complete blocks, with three replications. In the variable plant density, the control without application was the treatment with the highest weed density. Also, the best combination to inhibit weed emergence was Acetochlor with Flumioxazin. In addition, Flumioxazin alone or combined is among the treatments with the lowest density of weeds. Regarding the variable weed biomass and herbicide efficiency, all treatments were superior in efficacy to the control. Furthermore, the combination of Pendimethalin with Acetochlor had better performance with 0.253 kg m^{-2}. In the variable yield of the onion crop and weed index, the best combinations were Pendimethalin with Acetochlor and Oxifluorfen only with 2.97 and 2.92 kg m^{-2}, respectively. In contrast, the Flumioxazin treatment alone had lower performance. Regarding the loss of biological effectiveness of herbicides, it was found that, overall, due to the loss of effectiveness, an average of 674 individuals of weeds ha^{-1} appear daily.

Keywords: fertigation, herbicide, onion.

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Introduction

Onion is one of the most important agricultural crops worldwide, occupying the fifth place in production volume, with 117 076 053 t. Likewise, in Mexico, this vegetable occupies the third place with a production of 785 862 t. The production of this vegetable is limited by the competition exerted by the weeds. Weeds compete with crops of agricultural importance for limited resources, such as nutrients, light and space, mainly (Froud-Wiliams, 2008), which can cause onion yield to decrease between 40 and 80% (Prakash *et al*., 2000).

That is why it is important to control them, for which there are several alternatives, which include cultural control, manual control, chemical control and covers with organic material (Olayinka and Etejere, 2015).

Weeds have a greater competitive capacity than cultivated plants, such as growth speed, seed production, etc., so some control method is required (Jangre *et al*., 2018). To achieve greater efficiency, irrigation and fertilization management must be integrated.

Chemigation; through a drip irrigation system it supplies the chemicals directly to the area of interest. Due to the precision of application, chemigation can be less dangerous and use fewer chemicals than other application methods. Many of the common fertilizers and pesticides can be applied through the drip irrigation system (Shock and Welch, 2013; Gómez-Galvez *et al*., 2019).

In the development of this project, the following premises were taken as a basis: a) in the application of integrated weed management it is important to understand that the decision made to control them can affect the onion yield; b) competition in the early stages of onion development can cause substantial crop yield losses; c) that chemical herbicides are pollutants, therefore they should be used in the lowest possible doses; d) that, in evaluating the effect of weeds on crops, account should be taken of the densities of weed populations, the time of emergence and the time of removal; and e) that herbicides can cause onion phytotoxicity, for which it is necessary to determine the dose of the product, its formulation and what is the most appropriate phenological stage of the crop for its application. Some herbicides contain only one active ingredient; however, most are mixtures of at least two active ingredients.

Furthermore, in the search for greater efficacy in weed control, mixtures of two or more herbicides that have been formulated, independently of each other can be made; however, some mixtures can be antagonistic, causing damage to crops or reducing the efficiency in the control of some weeds (Caseley, 1996). Regarding chemical control, different alternatives are proposed, one of the most common is the use of herbicides.

The objective of the research work was to determine the effect of pre-emergent action herbicides in the control of weeds and the development of the onion crop under the fertigation system. The response variables to the different herbicide combinations were weed plant emergence along a time gradient, weed biomass production and crop yield. With this, a better solution was sought, to control weeds in onion cultivation under a drip irrigation system.

Materials and methods

Geographical location of the experiment

The experiment was carried out during the autumn-winter 2016-2017 cycle in a plot of the San Lorenzo Valley in Culiacán, Sinaloa, located at 24° 27’ 27.53’’ north latitude, 107° 16’ 02.32’’ west longitude of the meridian Greenwich and an altitude of 38 m (Google Earth, 2018).

Physical characteristics where the experiment was developed. The physical characteristics of the soil were determined by laboratory analysis, from which the irrigation sheet was estimated, as shown in Table 1.

Table 1. Physical characteristics of the soil to calculate the irrigation sheet.

Characteristics	Value
Clay (%)	27.96
Silt (%)	23.44
Sand (%)	48.06
Field Capacity (%)	21.2
Permanent wilting point (%)	10.6
Apparent density	1.282
Furrows width (cm)	80

Determination of the water needs of the onion

To estimate the distribution of the irrigations throughout the crop cycle, the consumptive use of the onion was adapted to the conditions of the planting date and the environmental conditions of the area of the experiment. For this, the closest meteorological station to the study was taken as the base, which in this case was the station located in the Quila Community, Culiacán, Sinaloa (Mexico), as shown in Table 2.

Table 2. Consumptive use of onion in Quila, Sinaloa.

Month	Precipitation (mm)	Temperature ºC	Kt	P	F	Kc	UC (cm)
November	9.6	24.8	1.978	8.09	14.69	0.75	11.02
December	50.32	21.84	1.669	7.43	12.45	1.08	13.44
January	20.2	20	1.514	7.46	11.48	0.9	10.33
February	21	20.2	1.590	7.58	11.4	0.7	7.98
Total							42.78

UC= consumptive use; Kt= temperature coefficient; P= percentage of light hours of the month; F= monthly value that is a function of temperature and (%) of light; Kc= development coefficient.

Onion fertilization

For the onion fertilization the drip irrigation system was used, for which appropriate fertilizers were applied for this type of irrigation. The amount of fertilizers was applied as indicated in Table 3.

Table 3. Fertilizers and doses used per hectare in onion cultivation.

Source	Formulation	Fertilizer (kg)	Total N	Nitrate	Ammonium	P	K	Ca	Mg	S
Monopotassium phosphate	0-52-34	25				13	8.51			
Potassium nitrate	12-00-46	75	9	9			34.5			0.9
Calcium nitrate	15-00-00-30	100	15	15				30.1		
Magnesium nitrate	11-00-00-16	175	19.25	19.25					28	
Ammonium phosphonitrate	33-04-00	500	165	82.5	82.5	20				
Phosphoric acid	0-52-0	125				65				
Potassium sulfate	0-0-52-17	125					65			21.3
Total			208.3	125.8	82.5	98	108	30	28	22.2

Experimental design

An experiment was carried out changing in pairs to five recommended herbicides in pre-sowing to control onion weeds. There were 16 treatments, including the control without herbicide application, as shown in Table 4. The experimental design was a randomized complete block experiment, with three replications.

Table 4. Treatments used in the experiment.

Treatment	Base herbicide	Complementary herbicide
1	Pendimethalin	Oxifluorfen
2	Pendimethalin	Acetochlor
3	Pendimethalin	Oxadiazon
4	Pendimethalin	Flumioxazin
5	Pendimethalin	solo
6	Oxifluorfen	Acetochlor
7	Oxifluorfen	Oxadiazon
8	Oxifluorfen	Flumioxazin
9	Oxifluorfen	solo
10	Acetochlor	Oxadiazon
11	Acetochlor	Flumioxazin
12	Acetochlor	solo
13	Oxad	Flumioxazin
14	Oxadiazon	solo
15	Flumioxazin	solo
16	Control without application	-

The experimental unit consisted of five grooves 3.5 m long by 4 m wide. Two rows of plants with a separation of 15 cm between them and 15 cm between plants were placed in each bed. Each groove presented a drip irrigation tape, with a 20 cm dropper separation and a water consumption of 0.5 L h^{-1} per dropper.

Data on weeds and cultivation were obtained from the three central furrows, leaving the furrows on the banks as a buffer zone (edge effect), as well as one meter from each end of the bed to be evaluated. In the control treatment, no manual or mechanical control of the weeds was performed. The doses applied for each type of herbicide were according to the corresponding technical data sheet. Which were used both when the herbicide was applied alone or in combination with another (Table 5).

Table 5. Dose of active ingredient applied by type of herbicide, according to the corresponding technical data sheet.

Active ingredient	Formulation	Concentration	Dose (active ingredient) per ha
Pendimethalin	Prowl® H_2O (encapsulated suspension)	455 g of ia L^{-1}	1 365 g
Oxifluorfen	Goal Tender TM (concentrated suspension)	480 g of ia L^{-1}	360 g
Acetochlor	Harness® (emulsifiable concentrate)	600 g of ia L^{-1}	1 500 g
Oxadiazon	Ronstar® 25 (emulsifiable concentrate)	250 g of ia L^{-1}	250 g
Flumioxazin	SumiMax® (dispersible granules)	510 g of ia kg^{-1}	153 g
Control without application			-

In the Table 6 describes the mode of action and chemical family of the herbicides used in this investigation.

Table 6. Herbicides according to the chemical family and mode of action to which they belong.

Active ingredient	Action mode	Chemical family (group)
Pendimethalin	Inhibition of mitosis	Dinitroaniline
Acetochlor	Inhibition of mitosis	Chloroacetamide
Oxifluorfen	Inhibition of protoporphyrinogen oxidase (PPO)	Diphenylether
Flumioxazin	Inhibition of protoporphyrinogen oxidase (PPO)	N-phenylphthalimide
Oxadiazón	Inhibition of protoporphyrinogen oxidase (PPO)	Oxadiazole

WSSA (2018).

The order of establishment of the crop was as follows: 1) application of the herbicide mixture to the soil; 2) application of irrigation. The irrigation tape with emitters arranged every 15 cm, with an expense of 0.5 L h^{-1}; 3) treatment of the bulb with fungicide (thiabendazole); and 4) transplantation of the bulb.

Weed density

To estimate the density of weeds, the number of weeds of the total species per m^2 was counted, the weed count was performed every week, for this the central 6 m^2 of each experimental unit (made up of 14 m^2) were considered, for which which, 6 squares of 1 m^2 each were formed with thread. As an inclusion criterion, the stem of the weed was considered to be within the table formed in the experimental unit (Kalhapure *et al*., 2013).

Weed biomass

To determine the biomass of weeds, these were dried in a drying oven at 80 ºC until obtaining a constant weight according to the technique suggested by Nielsen (2003). Weed harvesting was done at the end of the crop cycle. The dry weight of the plant was obtained using an electronic scale (0.1 mg precision).

Weed control efficiency

This variable was calculated according to the procedure proposed by Mani *et al*. (1973); (Ramalingam, 2013) from the following formula: $EFM\%= \frac{BMc\text{-}BMt}{BMc} * 100$, where: EFM= efficiency of weed control (%); BMc= biomass of weeds (g m^{-2}) in the control plot. BMt= weed biomass (g m^{-2}) in the treated plot.

Onion crop yield. The bulbs from each useful plot were harvested and weighed, from which the weed index was calculated, under the procedure proposed by Gill and Kumar (1969); (Ramalingam, 2013) from the following formula: $IM=\frac{X\text{-}Y}{X} * 100$, where: X= yield (kg ha^{-1}) of the plot without weed competition; Y= yield (kg ha^{-1}) of the experimental unit of the evaluated treatment.

Loss of biological effectiveness of herbicides

This variable was calculated based on the weed density, measured over the course of the experiment. With the obtained data, a linear regression analysis was performed (Zar, 2010), where the independent variable was time (in weeks) and the dependent variable was plant density.

Analysis of data

To analyze the data, a normality and homoscedasticity test was performed, to apply an analysis of variance of the density, biomass and onion yield; however, in the first two cases, the data did not have a normal distribution, although they were transformed. Regarding the crop yield, there was a normal distribution, but the homoscedasticity test showed that the variances were not equal. Given this situation, it was decided to carry out a non-parametric statistical analysis, applying the Kruskal Wallis test (Krebs, 1999).

To analyze the loss of biological effectiveness, a linear regression was performed, where the independent variable was the combination of the different pre-emergent herbicides along a time gradient, while the dependent variable was the plant density. Xlstat statistical software for Excel (Addinsoft, 2018) was used in this analysis.

Results and discussion

Weed density

The control without application was the treatment with the highest density of weeds, with 213 plants being statistically different from the rest of the treatments (Table 7). This means that applied herbicides have some degree of control in weed emergence. Furthermore, it is shown that the most effective combination to inhibit weed emergence was the combination of Acetochlor with Flumioxazin. In addition, it is striking that Flumioxazin alone or combined is among the herbicides with the lowest density of weeds.

Table 7. Multiple pairwise comparisons using Dunn's procedure/bilateral test in weed density control.

Treatment	Average number of weeds	Groups
Control without application	213	A
Pendimethalin only	66	AB
Oxifluorfen Oxadiazon	58	AB
Pendimethalin Oxadiazon	50	AB
Oxadiazon only	39	AB
Pendimethalin Flumioxazin	39	AB
Pendimethalin Acetochlor	37	AB
Oxifluorfen only	35	AB
Acetochlor only	34	AB
Oxifluorfen Acetochlor	33	AB
Pendimethalin Oxifluorfen	33	AB
Flumioxazin only	30	AB
Oxifluorfen Flumioxazin	22	AB
Acetochlor Oxadiazon	19	AB
Oxadiazon Flumioxazin	18	AB
Acetochlor Flumioxazin	12	B

This suggests that the most effective herbicide within the combinations is Flumioxazin combined with Acetochlor, without statistically differing from all chemical treatments. Flumioxazin, combined with Acetochlor, improves their action because they belong to groups with different modes of action, acting better on certain weed species.

In this regard, Labrada and Parker (1996), point out that different types of herbicides are used in onion weed control, depending on their type of control. However, the other variables evaluated in this investigation must be considered to conclude which is the best herbicide combination.

Weed biomass and herbicide efficiency

The analysis showed that all the treatments were better than the control. Furthermore, it is shown that the Pendimethalin plus Acetochlor treatment had better performance with respect to the variable biomass of weeds with 0.253 kg m^{-2} (Table 8).

Table 8. Multiple pairwise comparisons using the Dunn procedure/bilateral test and efficiency in weed control.

Treatment	LS Means (weed dry weight) (kg m^{-2})	Efficiency	Groups
Control without application	1.347	0	A
Pendimethalin only	1.284	4.693	AB
Pendimethalin Oxifluorfen	1.107	17.856	AB
Oxadiazon only	1.092	18.969	AB
Pendimethalin Oxadiazon	1.047	22.31	AB
Oxifluorfen Acetochlor	1.011	24.948	AB
Oxadiazon Flumioxazin	0.967	28.247	AB
Acetochlor Oxadiazon	0.958	28.866	AB
Pendimethalin Flumioxazin	0.873	35.175	AB
Flumioxazin only	0.778	42.268	AB
Acetochlor only	0.731	45.773	AB
Acetochlor Flumioxazin	0.667	50.515	AB
Oxifluorfen only	0.536	60.206	AB
Oxifluorfen Oxadiazon	0.478	64.536	AB
Oxifluorfen Flumioxazin	0.319	76.289	AB
Pendimethalin Acetochlor	0.253	81.196	B

One of the reasons that the combination of Pendimethalin with Acetochlor had less weed weight may be that they present different mechanisms of action, since the former inhibits the assembly of the micro tubules which are part of the skeleton of the cells, where they have multiple functions.

While Acetochlor belongs to the group that inhibits cell division (Megías *et al*., 2019). Furthermore, there is a combination between the two types of herbicides, since Pendimetalin mainly inhibits root development, while Acetochlor is absorbed mainly by coleoptyl and hypocotyl.

It was also found that some herbicides were more efficient acting alone than in combination with another, such is the case where Oxifluorfen was only better than combined with Acetochlor. In this regard, in a study by Villalba *et al*. (2010) in the control of weeds in eucalyptus, found that the combination of Oxifluorfen with Acetochlor was less efficient than Oxifluorfen alone, in the control of *Digitaria sanguinalis* grass.

Onion crop yield and weed index

Table 9 shows that the best combinations in onion yield were Pendimethalin plus Acetochlor, as well as Oxifluorfen only with 2.97 and 2.92 kg m^{-2} respectively. In contrast, treatment with Flumioxazin was only the herbicide with the lowest yield.

Table 9. Multiple pairwise comparisons using the Conover-Iman procedure/Bilateral onion yield test.

Category	LS Means (onion yield kg m^{-2})	Weed index	Groups
Pendimethalin Acetochlor	2.97	16.86	A
Oxifluorfen only	2.92	18.23	A
Pendimethalin Oxifluorfen	2.83	20.73	AB
Oxifluorfen Acetochlor	2.74	23.34	AB
Acetochlor Oxadiazon	2.62	26.48	ABC
Pendimethalin Oxadiazon	2.12	40.65	ABCD
Pendimethalin only	1.88	47.21	ABCD
Oxifluorfen Flumioxazin	1.67	53.17	ABCD
Acetochlor Flumioxazin	1.58	55.69	ABCD
Pendimethalin Flumioxazin	1.55	56.53	ABCD
Oxadiazon Flumioxazin	1.4	60.70	ABCD
Acetochlor only	1.37	61.64	ABCD
Oxifluorfen Oxadiazon	1.37	61.72	ABCD
Oxadiazon only	1.06	70.35	BCD
Flumioxazin only	0.9	74.68	CD
Control without application	0.61	83.01	D

It is striking that Flumioxazin was only the treatment with the lowest weight of the bulb. In this aspect, it must be considered what dose and what formulation of the herbicide can cause toxicity to the crop depending on its phenological stage (Akey and Sousa, 1985; Karnataka, 2007; Ramalingam *et al*., 2013). In the case of this herbicide, the technical data sheet indicates that the product should be applied about three days after transplantation.

This means that the herbicide was active at the time the bulb was placed on the soil treated with this herbicide, and that when the root arose it was damaged by the herbicide. Additionally, the University of California Integrated Management Program (Smith *et al*., 2019), notes that the herbicide Flumioxazin is recommended only for garlic, not for onion.

On the other hand, the results also show that not using herbicides, or any other control method, reduced yields 83%. This reinforces the approach of Prakash *et al*. (2000), regarding the loss of yield in the onion crop, caused by competition with weeds.

Loss of biological effectiveness of herbicides

When performing the analysis of variance of the regression, statistical significance was observed, with a value of p= 0.004839. Likewise, the R^2 value was 0.888 and a regression slope value of 0.6477 (Figure 1), which is equivalent to 674 new daily plants per hectare.

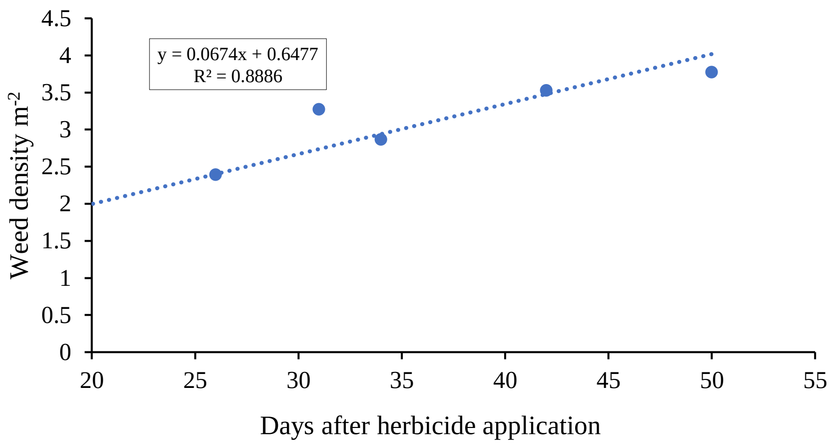

Figure 1. Relationship between the time of application of herbicides and the emergence of new weeds.

Regarding the density of weeds over time, it was observed that in all the treatments it decreases and then there is an increase in the density (Figure 2). This may be due to the fact that, those that emerge during the first days after the application of herbicides are born weak due to the action of the latter. Another reason may be competition for space between and among individuals of the same species (Begon *et al*., 2006).

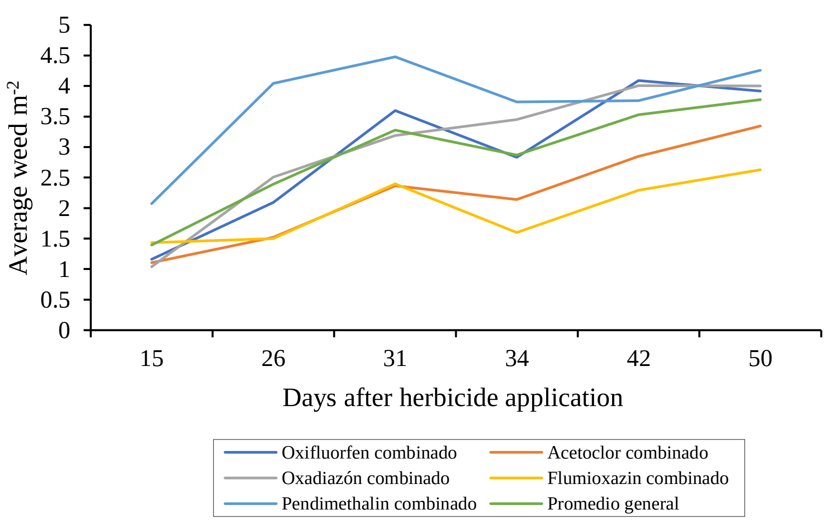

Figure 2. Efficiency of herbicides days after herbicide application.

The emergence of new weed individuals, apart from being related to loss of residuality, is also associated with their characteristics, since they have a discontinuous germination process (Baker, 1974); Altieri (1999), since the duration of the latency of the weed seed varies according to the biotype and the storage conditions of the seeds in the soil (Ferrero, 2004).

This loss of biological effectiveness reinforces the approach that after one herbicide applied in pre-transplantation another one is applied after transplantation. Likewise, the convenience of performing manual weed control is shown (Kalhapure *et al*., 2013). In addition to the above, the different combinations with Flumioxazin were the treatments that presented the lowest density of weeds, so it would be expected that this would be reflected in a higher weight of onions as part of the competition was eliminated; however, it was not.

This could be because this herbicide may have caused phytotoxicity in onion plants. In this regard, the technical data sheet of this product (Valent, 2017) indicates that Flumioxazin should be applied without combining it with other herbicides. It should also be taken into account that the dosage and formulation of the herbicide can cause toxicity to the crop depending on its phenological stage (Akey and Sousa, 1985; Karnataka, 2007: Ramalingam, *et al*., 2013).

Conclusions

The combination Acetochlor with Flumioxazin was the one that had better control in the density of the weeds, the latter being the herbicide with the lowest density of weeds. In the variable Biomass of weeds and herbicide efficiency, the combination of Pendimethalin with Acetochlor presents the best control, probably due to the fact that they have a different mode of action in the emergence of weeds. Which favored the yield of the onion.

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