Colegio de Postgraduados

Chemical Management of *Helianthus annuus* L. as a Broadleaf Weed in Interaction with the *Zea mays* L. Crop

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ABSTRACT

Objective: To evaluate the biological effectiveness of progressive doses of the herbicide Condraz® (tritosulfuron +dicamba) in post-emergence in dicotyledonous plants grown in consortium with corn in a greenhouse.

Design/methodology/approach: The research was performed out in a greenhouse within the facilities of the Colegio Superior Agropecuario del Estado de Guerrero. Dekalb 357® corn was established, planted in a consortium with sunflower, to measure the response to different dosages of the herbicide Condraz® (tritosulfuron+dicamba). We worked with a completely randomized block experimental design (DBCA).

Results: The treatments were 100% effective, because they eliminated the sunflower plants used as a representative of dicotyledonous weeds; while, in treatment T1 (water) the number of these was not affected, which was 10 sunflower plants per pot in the two experiments.

Limitations on study/implications: Our results are specific for the management of dicotyledonous weeds in corn.

Findings/conclusions: Condraz® herbicide is effective in eliminating dicotyledonous weeds when applied in doses ranging from 100 to 190 g per ha.

Keywords: weed, chemical control, herbicide

INTRODUCTION

Corn (*Zea mays* L.) is the most important cereal worldwide, surpassing rice and wheat in production volume (OECD/FAO, 2023). In 2022, global corn production reached 1,440 Mt, with Mexico producing 26.6 Mt, ranking sixth in the production of this cereal (FAOSTAT, 2024). In Mexico, corn is the most significant crop in terms of nutrition, gastronomy, and culture; it occupies more productive land than any other crop (De los Santos-Ramos *et al.*, 2017).

In Mexico, white corn production is primarily intended for human consumption; however, the country is not self-sufficient in supplying yellow corn, which is mainly imported from the United States (SAGARPA, 2017).

In every production cycle, there is the persistent issue of weed incidence, which directly affects the development of the corn plant. If left uncontrolled, weeds can lead to total crop loss (Sharma *et al.*, 2021). Weeds can be more harmful than any other pest (Idziak *et al.*, 2022); they actively compete for sunlight, water, nutrients, and space, causing damage to the phenology and morphology of the corn plant, thus affecting crop development and yield, resulting in economic losses (Sharma *et al.*, 2021).

There are cultural, chemical, mechanical, and biological methods for weed management (Rastgordani *et al.*, 2013), which are applied with the aim of suppressing the growth of weed flowers (Shahzad *et al.*, 2021). However, manual and cultural control methods require a significant amount of labor, which increases costs and is not always readily available (Perez-Ruiz *et al.*, 2013).

Currently, weed control in corn cultivation relies on the application of herbicides, which are effective and safe for ensuring crop development and yield (Waligóra *et al.*, 2012). The use of herbicides containing at least two active ingredients with different modes of action leads to control over a broad range of weed species, prevents damage by using lower herbicide doses, reduces residual effects in plants and soil, delays the onset of resistance, and lowers production costs (Idziak and Woznica, 2020). Due to these advantages, chemical control is the most effective and popular method for weed management (Martínez *et al.*, 2021). However, excessive use can contribute to the development of resistant species, which may affect crop quality or have an impact on the environment and health (Shahzad *et al.*, 2021). Globally, in 2022, 350 cases of glyphosate resistance were reported (Arispe-Vázquez *et al.*, 2023). Therefore, it is necessary to adopt strategies that help reduce this issue by using new molecules applied in optimal doses and at the appropriate time. Among the herbicides available in Mexico is Condraz® (tritosulfuron+dicamba), a systemic, post-emergence herbicide selective for controlling broadleaf weeds in corn and wheat crops; it exhibits rapid penetration into weeds, low residuality in the soil, minimal impact on the soil ecosystem, and is suitable for crop rotation (Çağlar *et al.*, 2023). The hypothesis of this study is that higher doses will have a greater control effect. Thus, the objective of the research was to evaluate the biological effectiveness of progressive doses of the herbicide Condraz® (tritosulfuron+dicamba) in post-emergence in dicotyledonous plants grown in consortium with corn in a greenhouse.

MATERIALS AND METHODS

Study Area

The research was conducted in a low-tech greenhouse located at the Superior Agricultural College of the State of Guerrero (CSAEGRO), situated at km 14.5 on the Iguala-Cocula road (18° 14' 00" N and 99° 40' 00" W, at an altitude of 640 m). This region has a warm sub-humid climate Awo (w) (i) g, with summer rains; the average annual precipitation and temperature are 797 mm and 26.4 °C, respectively (Ayvar *et al.*, 2021).

Genetic Material

The improved white corn hybrid Dekalb-357® (DK-357®) was used, which is a dual-purpose variety (grain and forage), adaptable to various regions, particularly tropical climates. The planting density was 50,000 to 60,000 seeds per ha^{-1}, with a germination and emergence rate exceeding 98%. The plant exhibits excellent foliar health, an average height of 250-260 cm, and 110 cm at the ear insertion; it begins flowering at 65-70 days and is harvested at 155-160 days. The ear coverage is good. The grain type is semi-dent and has 18 to 20 rows per ear (Reyna *et al.*, 2023). The sunflower (***Helianthus annuus***) variety Ekilore is an annual herbaceous plant with an average height of 2.5 meters, without branches. Its stem is hirsute, with alternate, large, ovate leaves with serrated margins. It has inflorescence in a large terminal capitulum, with yellow ligulate flowers on the exterior and dark florets in the center. The fruit is a grayish achene, usually with black bands (Girón, 2023).

Study Treatments

Corn Dekalb 357® was established in consortium with sunflower to measure the response to different doses of the herbicide Condraz® (tritosulfuron+dicamba). T1=water, T2=100 g per ha^{-1}, T3=115 g per ha^{-1}, T4=130 g per ha^{-1}, T5=155 g per ha^{-1}, T6=160 g per ha^{-1}, T7=175 g per ha^{-1}, and T8=190 g per ha^{-1}. Sunflower plants were included as a representative species of dicotyledonous weeds to assess the toxicity of the chemical molecules contained in this product.

Experimental Design and Units

The eight treatments, each with five replications, were arranged in a completely randomized block design (CRBD); a total of 40 experimental units were used. Each unit consisted of a black polyethylene pot with dimensions 11×11×15 cm, filled with 1.5 kg of substrate, one corn plant, and ten sunflower plants to recreate aspects of weed-crop interference, *i.e.*, to promote interspecific competition. The experiment was established in duplicate.

Greenhouse Characteristics

The crop was established in a bicentennial type of greenhouse with a white, waterproof plastic cover, with a thickness of 0.125 mm, tensile strength of 49 N, and puncture resistance of 62 N. The cover reflects 20 to 30% and absorbs between 70 and 80% of solar light (Reyna *et al.*, 2023).

Preparation of the Substrate and Pots

The substrate was prepared by mixing forest soil and sifted sand in a 1:1 ratio. A total of 80 pots (40 per experiment) were filled with this mixture. The pots were then weighed to standardize the substrate content to 1.5 kg per experimental unit.

Planting, Irrigation, and Fertilization

Before direct planting, the pots were watered to field capacity to provide the seeds with the appropriate conditions for emergence. Four corn seeds and 15 sunflower seeds were sown per experimental unit. Twenty-four hours after planting, manual watering was performed each morning to field capacity to keep the substrate moist and prevent water stress. Five grams of diammonium phosphate (DAP) (18-46-00) were applied per pot 15 days after planting (DAPL).

Application of Condraz® Doses

The herbicide was applied 21 days after planting (DAPL). The dose of the herbicide for each treatment was diluted in 350 mL of water. Manual spraying was carried out using a 500 mL plastic sprayer, where the liquid was shaken to homogenize it and then sprayed onto the foliage. The total spray volume was 2.0 mL per experimental unit, with only one application of the treatments being performed.

Study Variables

At the end of the experiment (36 DAPL), the study variables were measured, except for the plant's foliar coverage, which was evaluated three days after the application of the treatments.

Effectiveness Percentage

The number of surviving sunflower plants in each treatment was counted and then divided by the number of weeds present in the control (water). The result was multiplied by 100 to obtain the effectiveness percentage. The results were interpreted using the scale provided by the European Weed Research Society (EWRS) (Champion, 2000) (Table 1).

Table 1. Scale proposed by the European Weed Research Society (EWRS) to evaluate weed control.

Worth	Weed Control (%)	Effect on weeds
1	99.0 - 100.0	Deat
2	96.5 - 99.0	Very good control
3	93.0 - 96.5	Good control
4	87.5 - 93.0	Control sufficient
5	80.0 - 87.5	Control medium
6	70.0 - 80.0	Control regular
7	50.0 - 70.0	Control poor
8	1.0 - 50.0	Control very poor
9	0.0 - 1.0	Without effect

Phytotoxicity percentage. At the end of the experiment, the color tone of the plants in the control treatment (without application) was observed and compared with that of the plants in the other treatments.

Percentage of foliar coverage of corn and sunflower plants. A photograph was taken of the plants in each experimental unit (40 images), and the digital mobile application (Canopeo), developed using Matlab (Matrix Laboratory), was used to obtain foliar coverage. Measurement of this variable began three days after the treatments were applied, with four evaluations conducted at three-day intervals.

Height of corn plants (cm). The height was measured in centimeters, from the base of the stem to the apex of the last leaf.

Number of leaves per corn plant. Fully expanded leaves per plant were counted.

Fresh plant weight (corn and sunflower). Corn and sunflower plants were removed from the substrate and weighed using a digital scale. The data were recorded separately by species, treatment, and replication.

Dry plant weight (corn and sunflower). Corn and sunflower plants were separately placed in labeled paper bags and dried in an oven at 70 °C for 72 hours; they were then weighed on a digital scale independently.

Statistical analysis. An analysis of variance and multiple mean comparison test were performed using the Tukey method (α=0.05). Additionally, a linear regression and correlation analysis were conducted using SAS software (SAS Institute Inc., 2020).

Effectiveness Percentage. This variable showed highly significant differences because of herbicide application in both Experiment 1 (Pr>F=0.0001**) and Experiment 2 (Pr>F=0.0001**). It was determined that in both experiments, all treatments exhibited 100% effectiveness, as they eliminated the sunflower plants used as representatives of broadleaf weeds. Meanwhile, treatment T1 (water) did not affect the number of these plants, with 10 sunflower plants per pot in both experiments. The results suggest that the herbicide Condraz® effectively eliminates dicotyledonous weeds when applied at doses ranging from 100 to 190 g per ha^{-1}.

These results are similar to those of Tamayo *et al.* (2020), who achieved 92.5% effectiveness with the herbicide Condraz® for controlling broadleaf weeds 30 days after application (DAA) at a dose of 250 g per ha^{-1}, which is 150.0 to 131.6% higher than the dose used in the present study. Additionally, Çağlar *et al.* (2023) applied Condraz® at doses of 200 to 250 g per ha^{-1} at 21 DAA, achieving 85% effectiveness in controlling weed species such as *Chenopodium album* L., *Setaria verticillata* (L.) P. Beauv., and *Abutilon theophrasti* Medicus in corn cultivation. These effectiveness rates are lower than those obtained in the present study with lower concentrations in the applications.

Percentage of Phytotoxicity in Corn Plants

This variable did not show significant effects due to the application of treatments in Experiments 1 (Pr>F=0.4520NS) and 2 (Pr>F=0.4520NS). It was found that applications of Condraz® (tritosulfuron+dicamba) at the seven evaluated doses did not induce phytotoxic symptoms in corn plants DK 357®. These results align with those obtained by Tamayo *et al.* (2020), who determined that treatment with Condraz® at concentrations of 200 to 250 g per ha^{-1} in corn for the control of broadleaf weeds did not cause negative effects on the crop. The results agree with these authors, as it was confirmed that applications of the mentioned doses do not cause phytotoxicity problems in corn crops, both 7 and 15 DAA.

Corn Plant Height

The treatments caused significant differences in the average values of this variable, in Experiment 1 (Pr>F=0.0500*) and Experiment 2 (Pr>F=0.0442*). In Experiment 1, it was observed that the treatment with 160 g per ha^{-1} of Condraz® (T6) resulted in plants with greater height (average of 22.5 cm); however, it was only statistically different from the treatments with doses of 100 (T2) and 0 (T1) g per ha^{-1}, surpassing them by 18.7% and 8.4%, respectively (Table 2).

In Experiment 2, the treatments (T2) and (T7) with doses of 100 and 175 g per ha^{-1} of Condraz®, respectively, resulted in plants with the greatest height (average of 21.5 cm). However, no statistical difference was observed compared to the other treatments, including the control (T1); where the averages ranged between 17.3 cm (T1) and 21.3 cm (T6) (Table 2). According to these results, it is suggested that applying Condraz® at different doses can promote an increase in corn plant height, as it eliminates weed competition 36 days after emergence.

These results are consistent with those reported by Çağlar *et al.* (2023), who applied Condraz® (tritosulfuron+dicamba) at a dose of 250 g per ha^{-1} in corn crops for broadleaf weed control. They also noted that in the herbicide-treated plants, the maximum corn plant height was 27 cm, whereas the average height was 16 cm in the control, 21 DAA. Authors such as Martínez *et al.* (2021) mention that in weed-free conditions from the beginning of planting up to 10 days after emergence (dde), corn plants exhibit greater height due to the lack of competition.

Table 2. Height and number of leaves per corn plant.

Treatment	Height of corn plant (cm)		Number of leaves per plant	
	Experiment 1	Experiment 2	Experiment 1	Experiment 2
T1	18.30 b[†]	17.30 ab	7.00 a	6.40 b
T2	20.60 b	21.50 a	7.20 a	7.20 ab
T3	22.00 ab	20.30 a	7.80 a	7.20 ab
T4	21.80 ab	20.70 ab	7.40 a	7.40 ab
T5	22.20 ab	20.80 ab	7.40 a	7.40 ab
T6	22.50 a	21.30 ab	7.80 a	7.40 ab
T7	20.70 ab	21.50 a	7.20 a	8.20 a
T8	21.70 ab	21.00 ab	7.40 a	7.80 ab
DMS	4.12	4.12	0.85	0.38
Prob. F	0.0500*	0.0500*	0.4373NS	0.0500*

[†] Values whith the same letters in the same column are not statistically diferent. DMH: Tukey's mínimum honest difference α=0.05.

Number of leaves per corn plant

This characteristic, related to the plant's photosynthetic area, was not significantly affected in Experiment 1 (Pr>F=0.4373NS), but showed significant variations in Experiment 2 (Pr>F=0.0500*). In Experiment 1, it was determined that although all treatments with Condraz® doses (T2 to T8) resulted in plants with greater height compared to the control plants (T1), the differences in the number of leaves were not statistically significant and ranged between 7.2 leaves (T7) and 7.8 leaves (T3, T6); which were 2.9% and 11.4% higher than the 7 leaves in the control (Table 2).

In Experiment 2, it was observed that only the plants from the treatment with a dose of 175 g per ha^{-1} (T7) showed significantly greater heights than the control, with an average of 8.2 leaves, representing 28.1% more than the 6.4 leaves in the control (Table 2). The indicated dose of the herbicide may positively influence leaf formation per plant.

Martínez *et al.* (2021) observed that the number of leaves formed per plant decreases as the competition period between corn and weeds increases. This is an undesirable effect for plant productivity, as the number and size of leaves are determining factors for biomass production and grain yield in corn (Sánchez-Mendoza *et al.*, 2017). Based on this, it is important to consider that weed control in corn should be performed when the plant has between four and six leaves, because delaying control until the plant reaches ten leaves may lead to losses in production and economic income (Keller *et al.*, 2014).

Weight of corn plants (fresh and dry)

In this variable, the treatments had significant effects in both experiment 1 (Pr>F=0.0135*) and experiment 2 (Pr>F=0.0228*). In the first experiment, it was found that in the treatment with 160 g per ha^{-1} of Condraz® (T6), the plants had the highest averages with 69.6 g and 9.6 g for fresh and dry weight, respectively (Figures 1 and 2). However, these values were statistically different only from the control treatment T1 (35.6 g and 4.6 g for fresh and dry weight, respectively), exceeding it by 95.5% and 108.7% in weight (Figure 1).

In experiment 2, it was observed that in the treatments with Condraz® doses of 175 (T7) and 195 (T8) g per ha^{-1}, the plants reached the highest weights in both fresh (69.0 and 67.4 g) and dry (9.4 and 9.2 g) states. These were the two treatments that surpassed the control averages, which were 35.6 g and 4.0 g for fresh and dry weight. This indicates that, comparatively, the plants in T7 and T8 had weights that were 93.8% and 89.3% higher (fresh) and 135% and 130% higher (dry) than those in treatment T1 (Figure 1). The application of the highest doses of the herbicide was the most effective in significantly increasing the weight of the corn plants. These results differ from those reported by Tamayo *et al.* (2016), who determined that with applications of Condraz® at doses of 170 g per ha^{-1} in wheat cultivation, average weights ranged from 26.3 to 32.5 g for fresh plants and from 4.0 to 6.7 g for dry plants. However, the effects of the herbicide observed in the present study are similar to those of Vintimilla (2022), who evaluated the efficiency of herbicide mixtures for weed control in corn cultivation. Vintimilla noted that in the control treatment (without herbicide), the plants had lower weights due to the high incidence of weeds that exploited nutrients to the detriment of crop growth.

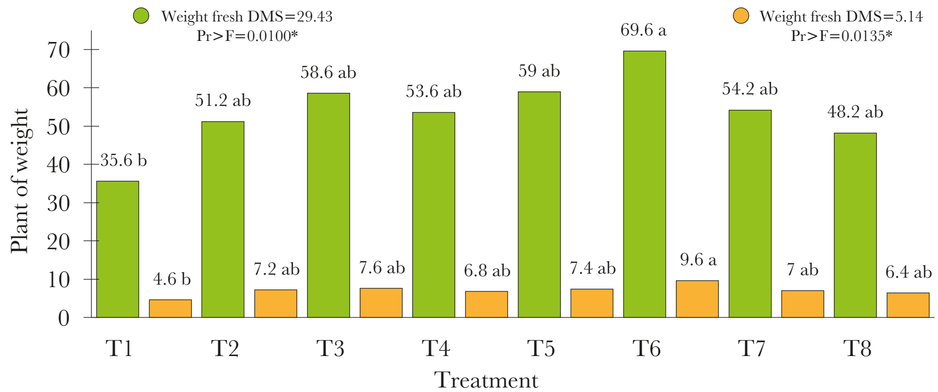

Figure 1. Effects of Condraz® (tritosulfuron+dicamba) doses on the fresh and dry weight of DK 357® corn plants at 36 days after planting (15 DAA) in Experiment 1. T1=Control (water), T2=Tritosulfuron+Dicamba (100 g ha^{-1}), T3=Tritosulfuron+Dicamba (115 g per ha^{-1}), T4=Tritosulfuron+Dicamba (130 g per ha^{-1}), T5=Tritosulfuron+Dicamba (145 g per ha^{-1}), T6=Tritosulfuron+Dicamba (160 g per ha^{-1}), T7=Tritosulfuron+Dicamba (175 g per ha^{-1}), T8=Tritosulfuron+Dicamba (195 g per ha^{-1}). DMS=Least Significant Difference of Tukey. Values with the same letters are not statistically different (Tukey, $\alpha \leq 0.05$).

Percentage of Leaf Cover of Corn Plants

The treatments caused highly significant differences in the evaluations conducted in Experiment 1, except in Evaluation 1 (Pr>Fc=0.1521NS), as well as in Experiment 2, except in Evaluation 1 (Pr>Fc=0.3916NS).

In Experiment 1, it was observed that the leaf cover behavior over time in Evaluations 2, 3, and 4 for the control treatment (no herbicide application) fit a linear regression model (R^2=0.96), with a 4.51% increase in leaf cover between each evaluation (Figure 2A). Similarly, in the treatments with Condraz® herbicide application, the model was similar (R^2=0.86), but with a 4.95% increase between evaluations (Figure 2B).

In Experiment 2, it was determined that the dynamics of leaf cover growth per plant in evaluations 2, 3, and 4 for the control treatment were represented by the linear regression model (R^2=0.94), with a 4.898% increase between evaluations (Figure 2C). In contrast, in the treatments with Condraz® herbicide application, the same model (R^2=0.76) indicated a 6.027% increase in cover between evaluations (Figure 2D). Based on these results, it can be stated that controlling dicotyledonous weeds with foliar application of Condraz® increased the leaf cover of corn plants by 9.7% to 23.1% compared to the control at 12 days after application (DDA). These results are similar to those reported by Callejas-Moreno *et al.* (2020), who found that in the control treatment (without herbicide application), weed cover was 72.5%, compared to an average of 25% in the herbicide-treated plots at 15 DDA.

Correlation Analysis

In Experiment 1, the response variables were highly significantly correlated (Pr>F=0.0001**). It was found that variables associated with plant growth, including height, collar diameter, number of leaves, and leaf cover, were positively and significantly associated with both fresh and dry plant weight. This is because as the plant grows, it tends

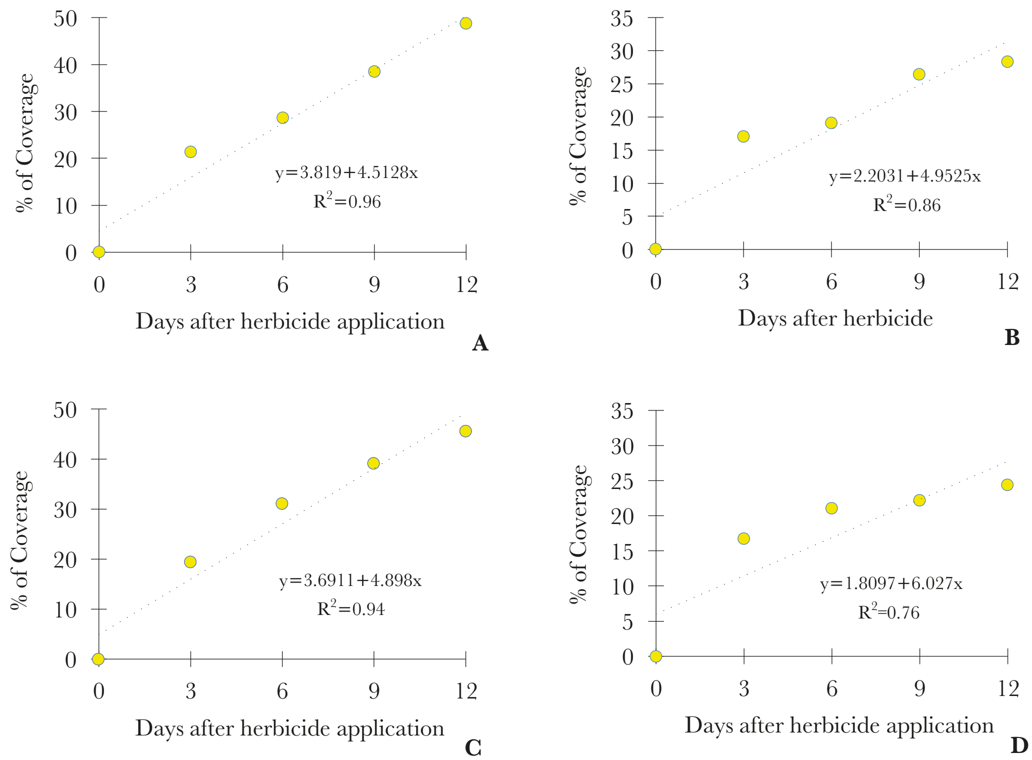

Figure 2. A. Linear regression model of leaf cover per corn plant in the control treatment in Experiment 1; B. Linear regression model of leaf cover per corn plant in the treatments with Condraz® herbicide application in Experiment 1; C. Linear regression model of leaf cover per corn plant in the control treatment in Experiment 2; D. Linear regression model of leaf cover per corn plant in the treatments with Condraz® herbicide application in Experiment 2.

to accumulate more biomass (Table 1). However, the correlation was negative between the percentage of phytotoxicity and both fresh plant weight and number of leaves, as herbicide-induced plant toxicity reduces plant development. There was also a negative and highly significant association between the number of live weeds and both height and fresh plant weight, as the presence of weeds negatively affects the increase in these two plant characteristics.

Table 3. Correlation analysis between response variables in Experiment 1.

	%E	% F	PF	PS	DT	A	NH
%F	0.42**						
PF	−0.41**	−0.36*					
PS	−0.40*	−0.35*	0.92**				
DT	-0.25^{NS}	−0.42**	0.72**	0.76**			
A	−0.47**	−0.45**	0.55**	0.58**	0.45**		
NH	-0.23^{NS}	−0.34*	0.65**	0.71**	0.69**	0.57**	
%CV	0.63**	0.26^{NS}	-0.29^{NS}	-0.30^{NS}	-0.08^{NS}	-0.26^{NS}	-0.14^{NS}

%E=Percentage of effectiveness. %P=Percentage of phytotoxicity. FW=Fresh weight of corn plants. DW=Dry weight of corn plants. SD=Stem diameter of corn plants. H=Height of corn plants. NL=Number of leaves per corn plant. %CV=Percentage of leaf coverage of the plant. NS=Not significant. *=Significant. **=Highly significant.

Table 4. Correlation Analysis between Response Variables of Experiment 2.

	%E	%F	PF	PS	DT	A	NH
%F	0.42**						
PF	−0.57**	−0.18^{NS}					
PS	−0.52**	−0.22^{NS}	0.90**				
DT	−0.60**	−0.24^{NS}	0.74**	0.68**			
A	−0.55**	0.33*	0.58**	0.60**	0.40**		
NH	−0.44**	−0.07^{NS}	0.74**	0.71**	0.61**	0.64**	
%CV4	0.77**	0.28^{NS}	−0.57**	−0.51**	−0.48**	−0.50**	−0.53**

%E=Percentage of effectiveness. %P=Percentage of phytotoxicity. FW=Fresh weight of corn plant. DW=Dry weight of corn plant. SD=Stem diameter of corn plant. H=Height of corn plant. NL=Number of leaves per corn plant. %CV=Percentage of foliar coverage of the plant. NS=Not significant. *=Significant. **=Highly significant.

In Experiment 2, the response variables were highly significantly correlated (Pr>F=0.0001). An interrelation of the variables similar to that observed in Experiment 1 was found; however, in this Experiment 2, the negative and highly significant correlation between the number of live weeds and the parameters, corn plant weight (fresh or dry), stem diameter, height, and number of leaves was more evident (Table 2). This is because these characteristics are negatively affected when weeds are growing in association with the economically important crop. These results are like those presented by Jamaica (2019), who reported that the crop exhibits better vegetative development in the absence of weeds.

CONCLUSIONS

The doses of Condraz® applied post-emergence did not show significant differences in biological effectiveness for eliminating dicotyledonous weeds growing in association with corn in the greenhouse. Low, medium, and high doses of Condraz® demonstrated 100% effectiveness in controlling dicotyledonous weeds. No dose of Condraz® caused phytotoxicity symptoms in corn plants. The control of dicotyledonous weeds with Condraz® increased the foliar coverage of corn plants by 9.7 to 23.1% compared to the control at 12 DAA. Growth variables correlated positively and significantly with the weight of corn plants. The incidence of dicotyledonous weeds correlated negatively with growth parameters and plant weight.

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