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Effects of Preemergence Herbicides on Bell Pepper, Crop Injury, and Weed Management in Irrigated Chilean Fields

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Bell pepper is an economically important vegetable crop that is often impaired by weeds. Management of weeds in bell pepper is required to minimize yield loss because this crop does not tolerate weed competition. Several herbicides have been reported as selective for bell pepper, but research supporting their use for weed control in this crop is limited. Several herbicides were screened in a greenhouse to assess effects on plant biomass, and eight were selected that appeared to be safe for bell pepper. These herbicides, in addition to oxadiargyl, were then evaluated at two different Chilean locations, using different application timings. We measured the effects on plant injury, fruit yield, and the need for additional hand weeding on transplanted bell peppers. The herbicides clomazone, napropamide, pendimethalin, and *S*-metolachlor caused minimal foliar chlorosis and necrosis but did not affect fruit yield at either location. Pretransplant-incorporated application (PTI) caused no effect on fruit yield from the herbicides evaluated, whereas applications 2 wk (POST2) and 8 wk (POST8) after transplanting reduced fruit yield significantly. For weed management, the best combination was PTI + POST2 + POST8, which reduced the hand-weeding time by 30% compared to the control, at both locations. Based on our results, clomazone, pendimethalin, and *S*-metolachlor were the most effective treatments applied after transplanting, whereas all herbicides tested were selective for bell pepper when applied and incorporated before transplanting. Results presented here provide new insight into herbicides that can be used to manage weeds in bell pepper and shows that timing of herbicide application is critical to prevent injury to this crop.
Nomenclature: Alachlor; bentazon; clomazone; fomesafen; halosulfuron-methyl; napropamide; oxadiazon; oxyfluorfen; pendimethalin; *S*-metolachlor; bell pepper, *Capsicum annuum* L.
Key words: Herbicide selectivity, pepper management, weed control.

El pimiento es un cultivo hortícola económicamente importante que es frecuentemente afectado por las malezas. El manejo de malezas en pimiento es necesario para minimizar las pérdidas de rendimiento porque este cultivo no tolera la competencia de las malezas. Varios herbicidas han sido reportados como selectivos para el pimiento, pero la investigación apoyando su uso para el control de malezas en este cultivo es limitada. Varios herbicidas fueron evaluados en un invernadero para determinar los efectos en la biomasa de la planta, y de estos se seleccionaron ocho herbicidas que parecían ser seguros en el pimiento. Estos herbicidas, además de oxadiargyl, fueron evaluados en dos localidades diferentes de Chile, usando diferentes momentos de aplicación. Nosotros medimos los efectos en el daño a la planta, el rendimiento de fruto, y la necesidad de desmalezado manual adicional en pimiento trasplantado. Los herbicidas clomazone, napropamide, pendimethalin, y *S*-metolachlor causaron clorosis y necrosis foliar mínimas, pero no afectaron el rendimiento de fruto en ninguna de las localidades. La aplicación incorporada pre-trasplante (PTI) no causó ningún efecto en el rendimiento de fruto producto de los herbicidas evaluados, mientras que aplicaciones 2 semanas (POST2) y 8 semanas (POST8) después del trasplante redujeron el rendimiento de fruto significativamente. Para el manejo de malezas, la mejor combinación fue PTI + POST2 + POST8, la cual redujo el tiempo de deshierba manual en 30% al compararse con el testigo, en ambas localidades. Con base en nuestros resultados, clomazone, pendimethalin, y *S*-metolachlor fueron los tratamientos aplicados después del trasplante más efectivos, mientras todos los herbicidas evaluados fueron selectivos al pimiento cuando fueron aplicados e incorporados antes del trasplante. Los resultados presentados aquí brindan nueva información acerca de los herbicidas que pueden ser usados para manejar malezas en la producción de pimiento y muestran que el momento de aplicación de herbicidas es crítico para prevenir el daño a este cultivo.

Bell pepper is an important crop worldwide, with almost two million ha (FAOSTAT 2012). In Chile, production is mainly for the domestic market; however, pepper seed exports during 2012 were valued at US$21 million (SAG 2012). Total production area during 2007 to 2012 averaged

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1,340 ha yr^{-1}, with an annual average production equal to 37 t ha^{-1} (ODEPA 2013). Bell pepper is a summer crop grown mostly by small growers. Approximately 76% of the land used for this crop is located between Coquimbo (31.00°S, 71.00°W) to O'Higgins' (34.16°S, 70.83°W) regions. Chilean growers rotate bell pepper with a variety of vegetable crops, such as broccoli, cabbage, onions, or corn. This cropping system relies entirely on irrigation, generally using gravitational systems. Transplanting occurs in October, mainly by hand, with an increased use of plugs in place of bare-root plants; and harvesting continues as long as markets prevail and until freezing conditions damage the crop.

The presence of summer annual and perennial weeds affects bell pepper plants. Several studies have shown that bell pepper is a poor weed competitor (Labrada and Paredes 1983; Lee and Schroeder 1995). More recently, Fu and Ashley (2006) remarked that redroot pigweed (*Amaranthus retroflexus* L.) and hairy galinsoga (*Galinsoga quadriradiata* Cav.) reduced bell pepper yield as much as 88% and 99%, respectively. Purple nutsedge (*Cyperus rotundus* L.), reduced bell pepper yield by as much as 70% (Morales-Payan et al. 2003). The long production season promotes weed emergence during bell pepper establishment and consequently resulted in a 97% yield loss and 92% stand loss (Amador-Ramírez 2002). Also, early weed interference during the first month after pepper emergence reduced yield 70% (Eshel et al. 1973).

Chilean farmers have few options to control weeds in bell pepper. Most frequently used is tillage, which is generally followed by cultivation after transplanting, herbicide application and hand weeding. Plastic mulch is not used extensively, due to high material and labor costs for installation. The herbicides labeled for bell pepper in Chile are mostly effective against grass weeds, including pendimethalin, *S*-metolachlor, and trifluralin (SAG 2014). Studies conducted in Mexico and the United States, evaluated several herbicides and different application timings for bell pepper such as bentazon, clomazone, napropamide, and halosulfuron (Amador-Ramírez et al. 2007; Robinson et al. 2008). Additionally, to increase the weed control efficacy, combinations of herbicides have also been tested. For example, combinations of alachlor, oxadiazon, and linuron resulted in fruit yield comparable to peppers that were kept weed-free all season (Adigun et al. 1991). Applications of fomesafen or *S*-metolachlor followed by imazosulfuron controlled nutsedge (*Cyperus* spp.) in bell pepper (Miller and Dittmar 2014). However, others have reported crop injury and yield reductions in direct-seeded and transplanted bell pepper plants following treatment with these herbicides (Lanini and LeStrange 1991; Medina 1995).

Therefore, due the limited alternatives for weed control, concerns about crop injury, and the increasing cost of hand weeding, this research was conducted to determine the pepper selectivity and efficacy of several herbicides. Specifically, we assessed effects of application timings of soil-active herbicides on crop injury, weed control, and fruit yield in transplanted bell pepper grown under furrow-irrigated conditions.

Materials and Methods

Preliminary Herbicide Selectivity Assay. Experiments were conducted in a greenhouse located at the San Joaquín campus of the Pontificia Universidad Católica de Chile (33.48°S; 70.60°W), during September and October of 2007 using bell pepper plants var. 'Resistant'. Seedlings were transplanted into 3-L plastic containers using a sandy loam soil with 54% sand, 27% silt, 17% clay, and 1.2% organic matter. Pots were fertilized with an elemental ratio of 97 : 90 : 20 nitrogen : phosphorous : potassium (NPK), using potassium nitrate (13–0–46) and triple superphosphate (0–46–0) as nutrient sources. All pots were watered daily as needed during the entire experiment.

Ten herbicides were applied at the following rates (kg ai ha^{-1}): alachlor (1.92), bentazon (1.2), clomazone (0.25), fomesafen (0.38), halosulfuron-methyl (hereafter referred to as halosulfuron), (0.08), napropamide (1.8), oxadiazon (0.63), oxyfluorfen (0.24), pendimethalin (1.62), and *S*-metolachlor (2.9). Each herbicide was applied at two different pepper growth stages. The first stage was sprayed 2 d before transplanting (PTI) to pepper seedlings with three true leaves; and the second stage was sprayed at 4 wk POST transplanting (POST4), when pepper seedlings had six true leaves. A nontreated control was included for comparison. Herbicides applied PTI were mechanically incorporated a depth of 10 cm with a hand tool, whereas POST4 herbicide treatments were

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Table 1. Field trial activities at Lonquén and Rengo sites in Chile.

Activities	November	December	January	February	March	April
Crop practices[a]						
Transplanting	X					
Hand weeding		X	X	X		
Harvesting						X
Herbicide treatment						
PTI	X					
PTI + POST 2	X	X				
PTI + POST 2 + POST 8	X	X	X			
POST 2 + POST 8		X	X			
Rating						
Chlorosis		X	X		X	
Necrosis		X	X		X	

[a] Abbreviations: PTI, pretransplant incorporated; PTI + POST2, pretransplanted incorporated followed by another POST application 2 wk after treatment (WAT); PTI + POST2 + POST8, pretransplanted incorporated followed by a POST application 2 WAT and another POST application 8 WAT; POST2 + POST8, POST application 2 WAT plus another POST application at 8 WAT.

applied using a CO_2-pressurized backpack sprayer, calibrated to deliver 138 L ha^{-1} using a single flat-fan nozzle 11001 anti-drift Airmix (Agrotop Spray Technology, Köferinger Str. 5, 93083 Obertraubling, Germany).

Potted plants were arranged in a randomized complete block design with five replications per treatment. Within each block, 22 plants were used for 11 treatments (10 herbicides plus the untreated control) and two application stages. Height and biomass was measured 9 wk after transplanting (WAT), when potted pepper plants were harvested. Data were subjected to ANOVA using PROC GLM in SAS v 9.3 (SAS Institute Inc., P.O. Box 8000, Cary, NC 25712) and means were separated using a Fisher's protected LSD ($\alpha \leq 0.05$). Because there was a significant interaction between application stages and herbicide ($P \leq 0.001$), data were analyzed for all herbicides within each application stage.

Field Trials. A followup experiment was conducted at two field locations, Lonquén (34.10°S; 70.60°W) and Rengo (34.41°S; 70.86°W), between November 2007 to April 2008. The Lonquén trial was established on a silt loam soil (16% sand, 52% silt, 29% clay) and 2.8% organic matter; whereas the Rengo site had a silty clay soil (1% sand, 37% silt, 57% clay) and 4.6% organic matter content. Both experimental sites were moldboard plowed, disked, and leveled prior to crop transplanting, according to standard production practices for the region.

At both locations, on December 3 and 6, 2007 (Lonquén and Rengo, respectively), four-leaf pepper seedlings var. 'Resistant' were hand transplanted in rows 0.75 m wide at a population density equal to 66,667 plants ha^{-1}. Plots measured 5 m long with three rows, and water was supplied by furrow irrigation throughout the growing season. Crop nutrients were band-applied and split into three equal doses each at planting, 15 and 45 d after transplanting. Fertilizers were applied at rates of 220 kg ha^{-1} of N, 60 kg ha^{-1} of P, and 330 kg ha^{-1} of K at Lonquén and 115 kg ha^{-1} of N, 70 kg ha^{-1} of P and K at Rengo.

Based on the preliminary herbicide selectivity assay, eight herbicides plus oxadiargyl were selected for field evaluation. Herbicides were applied at the following rates (kg ai ha^{-1}): bentazon (1.2), clomazone (0.25), halosulfuron (0.08), napropamide (1.80), oxadiazon (0.63), oxyfluorfen (0.24), pendimethalin (1.62), *S*-metolachlor (2.90), and oxadiargyl (0.40). As described in the Table 1, each herbicide treatment was applied at four timings: PTI (November 25, 8 or 11 d before transplanting); PTI + POST2; PTI + POST2 + POST8; and POST2 + POST8. Different timing combinations were assessed to compare their soil behavior, foliar activity, and effectiveness of all herbicides.

The experimental design was a split-plot design with herbicide as the main plot and spraying time as the subplot. Four replications per treatment were utilized, for a total of 40 main plots arranged randomly within each block. A nontreated control

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Table 2. Aboveground plant biomass (per plant) of greenhouse-grown bell pepper at 9 wk after treatment (WAT).[a]

Treatment		PTI[b]	POST4[b]
	kg ai ha^{-1}	g plant^{-1}	
Nontreated control	—	4.81 ab	4.81 ab
Alachlor	1.92	2.70 cd	0.86 d
Bentazon	1.20	5.04 a	0.52 d
Clomazone	0.25	4.14 abc	5.04 ab
Fomesafen	0.38	0.80 e	1.40 cd
Halosulfuron	0.08	3.50 abcd	4.48 ab
Napropamide	1.80	2.96 bcd	6.18 a
Oxadiazon	0.63	0.78 e	3.86 b
Oxyfluorfen	0.24	3.26 abcd	4.82 ab
Pendimethalin	1.64	4.44 abc	3.08 bc
S-metolachlor	2.88	1.86 de	4.74 ab

[a] Abbreviations: PTI, pretransplant incorporated; POST4, 4 wk posttransplant.

[b] Means followed by the same letter within a column are not significantly different according to a Fisher's protected LSD ($\alpha \leq 0.05$).

was also included for comparison. All treatments were hand weeded at 4, 7, and 10 WAT. All herbicide treatments were applied in water with a backpack sprayer equipped with four 11001 anti-drift nozzles (Agrotop Spray Technology). Spray volumes at Lonquén and Rengo ranged from 127 to 185 L ha^{-1} for PTI, and 190 to 244 L ha^{-1} for POST applications. PTI herbicides were incorporated mechanically into the soil at a depth of 10 cm with cultivation before transplanting. Herbicides applied at POST2 and POST8 were sprayed directly over pepper plants, as described in the greenhouse assay. Crop injury estimates were collected at 4 and 10 WAT. Overall plant injury was measured in each plot as foliar chlorosis percentage at 4 WAT and as percentage of foliar necrosis at 10 WAT. Thus, overall injury and plant foliar necrosis were a synthesis of effects noted on the entire plant. Additional hand weeding was completed when 30% of bare soil was covered by weeds. Those data were used to calculate the hours needed to maintain the critical period of weed control (CPWC) (Amador-Ramirez 2002).

The middle row of each plot was harvested to determine crop yield. Peppers were hand-picked and fruits were graded as marketable and nonmarketable to measure yield (t ha^{-1}). Fruits showing a fully and clean red color with no spots were classified as marketable, whereas fruits showing partially red or damaged fruit (mechanical damage, spots, deformations, scabs, etc.) were rejected and classified as nonmarketable. Results were presented as total yield because there was no significant effect on fruit quality.

As previously described, data were subjected to ANOVA using GLM in SAS and means were separated using a Fisher's protected LSD ($\alpha = 0.05$). Because significant interactions ($P < 0.001$) occurred for location and timing of herbicides application, data of overall plant injury, percentage of foliar necrosis, additional hand-weeding hours, and total yield were presented separately for each location.

Results and Discussion

Preliminary Herbicide Selectivity Assay. Data presented in Table 2 show significant effect of application time (PTI and POST4) on plant biomass at 9 WAT. Alachlor, fomesafen, napropamide, oxadiazon, and *S*-metolachlor reduced plant biomass applied at PTI. Alachlor was phytotoxic when applied at PTI and POST4, but the injury was more evident at POST4. On the other hand, the highest aboveground biomass was observed in peppers transplanted into soils previously treated with clomazone, halosulfuron, pendimethalin, napropamide, and oxyfluorfen at PTI as well as those sprayed with POST4; these showed similar biomass compared with nontreated control plants. Porter (1991) and Ackley et al. (1998) also found high selectivity of clomazone applied PTI at rates up to 1.12 kg ha^{-1} in peppers grown in silt loam soils. Similarly, Grey et al. (2001, 2002) reported a high plant tolerance and fruit yield in 'Yolo wonder' and 'Jupiter' following clomazone application over the plant canopy. Pendimethalin was similarly selective to pepper when applied at PTI as reported by Kogan (1992). Baltazar et al. (1984), Harrison and Ferry (1989), and Wolf et al. (1989) stated that bentazon must be used at rates not higher than 1.1 kg ha^{-1} to avoid phytotoxicity when applied 2 WAT. According to Schroeder (1992), phytotoxic effect of *S*-metolachlor in pepper might be associated with environmental factors such as soil temperature and soil moisture after transplanting.

In summary, these results indicate that alachlor and fomesafen caused unacceptable injury to pepper at either PTI or POST4, so they were excluded from further assessments. The herbicides with the

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Table 3. Percentage of foliar chlorosis on bell pepper plants after 4 wk after treatment (WAT) with different herbicides at Lonquén and Rengo, Chile locations.[a]

Treatment	PTI[b]		PTI + POST2[b]	
	Lonquén	Rengo	Lonquén	Rengo
	%			
Bentazon	56.25 ab	25.00 a	75.00 a	34.50 b
Clomazone	18.75 bc	12.50 a	25.00 b	25.00 b
Halosulfuron	62.50 ab	18.75 a	56.25 ab	62.50 a
Napropamide	25.00 bc	18.75 a	25.00 b	25.00 b
Oxadiargyl	62.50 ab	6.25 a	43.75 ab	28.25 b
Oxadiazon	43.75 abc	25.00 a	43.75 ab	37.50 b
Oxyfluorfen	75.00 a	18.75 a	87.50 a	56.25 a
Pendimethalin	6.25 c	6.25 a	12.50 b	0.00 c
S-metolachlor	37.50 abc	6.25 a	18.75 b	22.00 b

[a] Abbreviations: PTI, pretransplant incorporated; PTI + POST2, pretransplanted incorporated follow by another POST application 2 wk after transplant (WAT).

[b] Data followed with same letter within each column are not significantly different according the Fisher's protected LSD ($P \leq 0.05$).

lowest phytotoxic effect were clomazone, halosulfuron, and oxyfluorfen. Those three herbicides, at either PTI or POST4 applications, did not result in differences in plant biomass compared to nontreated plants.

Field Trials. According to the preliminary data obtained from the selectivity assay there was no clear pattern regarding the time of herbicide application. Therefore, field trials considered more application times, such as POST2 and POST8 and combinations (Table 1). In addition, the herbicide oxadiargyl was included because it was reported to be safe to pepper (Abdelhamid and El-Metwally 2008).

Foliar chlorosis differed by location (Table 3). In fields with low organic matter, more herbicide was available in the soil solution and higher phytotoxicity was observed (Barriuso et al. 1994; Felix and Doohan 2005; Nam et al. 1998). Therefore, transplanted peppers treated at Lonquén (2.8% OM), exhibited higher overall plant chlorosis than plants from Rengo (4.6% OM) at 4 WAT. The application timing effect over plant injury shown as foliar chlorosis on transplanted peppers at Lonquén did not vary among spraying times for the different herbicides, except for *S*-metolachlor. Napropamide, pendimethalin, and clomazone caused the least plant at injury the PTI and PTI + POST2 timings. Treatments with these herbicides caused slight foliar chlorosis (rating less than 1, meaning less than 25% foliar chlorosis). Similar results have been documented for these herbicides (Adigun et al. 1991; Robinson et al. 2008; O'Connell et al. 1998; Rajkumara et al. 2009). Highest plant injury (higher than 50% foliar chlorosis) was found in plants sprayed with oxyfluorfen, followed by bentazon and halosulfuron; this is similar to previous studies documented by Schroeder (1992), Grey et al. (2001, 2002), and Rajkumara and Palled (2009).

The herbicides applied before transplanting (PTI) generally were safe to pepper plants at the Rengo location (Table 3); the best performance was for pendimethalin, which caused of the least injury. In contrast, sequential applications (PTI + POST2) produced intermediate phytotoxicity (higher than 25% foliar chlorosis) in plants treated with bentazon, clomazone, napropamide, oxadiargyl, and oxadiazon. Severe crop damage (higher than 50% foliar chlorosis) was observed on plants sprayed with halosulfuron and oxyfluorfen.

Because there were significant differences between application times observed for plant chlorosis at Rengo, we added another two spraying timings (PTI + POST2 + POST8 and POST2 + POST8) to confirm this trend. Foliar necrosis at 10 WAT varied depending on the spraying time (Table 4). None of the herbicides sprayed at PTI or PTI + POST2 (with exception of oxyfluorfen at Lonquén) caused foliar necrosis, even though different levels of chlorosis were produced by some of the herbicides at 4 WAT (Table 3). Plants sprayed at POST2 + POST8 and PTI + POST2 + POST8 with oxyfluorfen and oxadiazon were injured and showed plant foliar necrosis ranging from 40 to 90%. In particular, oxadiargyl and oxadiazon showed different responses among locations, with higher necrosis on peppers grown at Lonquén. Low organic matter percentage at Lonquén, compared to that at Rengo likely was the reason for these differences.

Chlorosis observed at 4 WAT was not reflected later in foliar necrosis at 10 WAT due to recovery from phytotoxic effects of several herbicide treatments. In contrast, treatments that included applications at 8 WAT were very injurious to pepper (data not shown). Taken together, our results show that clomazone, napropamide, pendimethalin, and *S*-metolachlor could be considered the least phytotoxic herbicides, and the other

Table 4. Plant injury as percentage of foliar necrosis on transplanted bell pepper at 10 wk after treatment (WAT).[a]

Treatment	PTI		PTI + POST2		PTI + POST2 + POST8[b]		POST2 + POST8[b]	
	L	R	L	R	L	R	L	R
	%							
Nontreated	0	0	0	0	0 c	0 c	0 b	0 c
Bentazon	0	0	0	0	3.8 c	0 c	5 b	0 c
Clomazone	0	0	0	0	0 c	0 c	0 b	0 c
Halosulfuron	0	0	0	0	5.0 c	0 c	5 b	0 c
Napropamide	0	0	0	0	0 c	0 c	0 b	0 c
Oxadiargyl	0	0	0	0	21.3 b	3.3 c	18.8 b	3.3 c
Oxadiazon	0	0	0	0	90.0 a	40.0 b	90.0 a	40.0 b
Oxyfluorfen	0	0	21.3	0	87.5 a	80.8 a	67.5 a	80.0 a
Pendimethalin	0	0	0	0	6.3 c	0 c	6.25 b	0 c
S-metolachlor	0	0	0	0	7.5 c	3.5 c	8.75 b	4.0 c

[a] Abbreviations: WAT, weeks after treatment; PTI, pretransplant incorporated; PTI + POST2, pretransplanted incorporated followed by another POST application 2 WAT; PTI + POST2 + POST8, pretransplanted incorporated followed by a POST application 2 WAT and another POST application 8 WAT; POST2 + POST8, POST application 2 WAT plus another POST application at 8 WAT; L = Lonquén, Chile; R = Rengo, Chile.

[b] Data followed with same letter within each column are not significantly different according the Fisher's protected LSD ($P \leq 0.05$).

herbicides were very injurious when applied at PTI or PTI + POST2 (Table 3).

Hours required for hand weeding by each herbicide treatment, at both Lonquén and Rengo locations, are presented in Table 5. Hand-weeding times were significantly different at each location, with Rengo plots requiring longer weeding times than Lonquén. This might have been due to the field's cropping history, because Lonquén was cropped in previous years with different vegetables (spinach, tomatoes, etc.), whereas Rengo was not cultivated in the past 10 yr, allowing the weed density to build up. Thus, nontreated plots at Rengo needed more than 400 h of hand-weeding, while similar plots at Lonquén needed half that amount of labor. The lowest amount of weeding hours at Rengo was recorded in plots treated with pendimethalin and *S*-metolachlor, with 56 and 35% fewer hours than plots without herbicides, respectively. It is important to note that these herbicides caused the least plant damage, as shown in Tables 3 and 4.

Similar results are presented in Table 6 relative to total hours of hand-weeding for the different

Table 5. Total hours of hand weeding by each herbicide treatment for bell peppers at two locations in Chile.

Treatment	Lonquén[a]	Rengo[a]
	$h\ ha^{-1}$	
Nontreated	225.6 b	434.4 a
Bentazon	201.6 ab	368.0 bc
Clomazone	173.6 b	356.8 bcd
Halosulfuron	239.2 b	311.2 de
Napropamide	188.0 ab	389.6 ab
Oxadiargyl	213.6 b	320.0 de
Oxadiazon	293.6 ab	348.0 bcd
Oxyfluorfen	247.2 a	342.4 cd
Pendimethalin	188.8 ab	192.0 f
S-metolachlor	153.6 b	280.8 e

[a] Data followed with same letter within each column are not significantly different according the Fisher's protected LSD ($P \leq 0.05$).

Table 6. Main effects of herbicides spraying times on additional hand weeding needed for bell peppers ($h\ ha^{-1}$) in Chile.

Treatment[a]	Lonquén[b]	Rengo[b]
	$h\ ha^{-1}$	
Nontreated	252.8 a	434.4 a
PTI	211.2 ab	368.0 b
PTI + POST2	215.2 ab	304.0 b
PTI + POST2 + POST8	168.0 b	300.0 b
POST2 + POST8	229.6 a	319.2 b

[a] Abbreviations: PTI, pretransplant incorporated; PTI + POST2, pretransplanted incorporated followed by another POST application 2 wk after transplant (WAT); PTI + POST2 + POST8, pretransplanted incorporated followed by a POST application 2 WAT and another POST application 8 WAT; POST2 + POST8, POST application 2 WAT plus another POST application at 8 WAT.

[b] Data followed with same letter within each column are not significantly different according the Fisher's protected LSD ($P \leq 0.05$).

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Table 7. Total fruit yield of bell pepper plants applied with different combinations of herbicide treatments.[a,b]

Treatment	PTI		PTI + POST2		PTI + POST2 + POST8		POST2 + POST8	
	L	R	L	R	L	R	L	R
	kg ha^{-1}							
Nontreated	89 a	32 b	67 a	41 a	22 a	38 a	37 a	24 a
Bentazon	53 a	29 ab	31 abc	23 bc	19 cd	11 cd	8 e	19 cd
Clomazone	48 a	39 a	43 abc	49 a	55 a	35 ab	56 a	39 a
Halosulfuron	42 a	31 ab	52 ab	6 e	23 cd	10 cd	11 de	8 de
Napropamide	56 a	29 ab	62 ab	35 ab	51 ab	26 ab	51 a	26 abc
Oxadiargyl	44 a	43 a	55 ab	22 bcd	27 bcd	22 bc	30 bcd	22 bcd
Oxadiazon	58 a	24 ab	55 ab	18 cde	8 cd	8 d	17 cde	8 de
Oxyfluorfen	54 a	30 ab	22 bc	15 cde	3 d	9 d	0 e	4 e
Pendimethalin	55 a	26 ab	46 abc	34 ab	32 abc	34 ab	36 abc	21 bcd
S-metolachlor	65 a	40 a	43 abc	29 abc	53 ab	37 a	40 ab	35 ab

[a] Abbreviations: PTI, pretransplant incorporated; PTI + POST2, pretransplanted incorporated followed by another POST application 2 wk after treatment (WAT); PTI + POST2 + POST8, pretransplanted incorporated followed by a POST application 2 WAT and another POST application 8 WAT; POST2 + POST8, POST application 2 WAT plus another POST application at 8 WAT.

[b] Data followed with same letter within each column are not significantly different according the Fisher's protected LSD ($P \leq 0.05$).

combinations of herbicide spraying times. At Lonquén, there were no significant differences compared with the control, except for PTI + POST2 + POST8. Overall, the best combination was PTI + POST2 + POST8, with a reduction in the number of hours of hand-weeding of about 30% compared to nontreated plots in both locations. None of the pretransplant-incorporated applications were effective alone, and all required other applications, especially at Lonquén.

The effect on fruit yield caused by the combination of different herbicide treatments is presented in Table 7. In general, fruit yields were different between locations, mainly because of the number of harvesting times based on labor availability. However, both locations behaved similarly when yield was compared with their respective controls, except for PTI + POST2. For example, herbicide incorporation before transplanting caused no effect on fruit yield for both locations. In contrast, treatments that included herbicide applications at 8 WAT reduced yield. Clomazone, napropamide, pendimethalin, and *S*-metolachlor did not affect fruit yield in the four treatment combinations evaluated at either location. The lowest pepper yields were from plants that received POST applications (2 or 8 WAT) with halosulfuron, oxyfluorfen, and oxadiazon at both locations. Plants treated with oxadiargyl at 8 WAT had 20% lower yield compared with control plots.

Results indicate that pendimethalin was the best herbicide alternative, considering total fruit yield and hand weeding, with a 50% reduction in weeding hours compared to nontreated plots. *S*-metolachlor was also very selective with a high yield, and it required 35% less weeding than the control. Clomazone was also selective, with a 20% reduction in weeding hours compared to nontreated plots. According to statistical analysis of main effects, the best application timings were at PTI + POST2 and PTI + POST2 + POST8, which required the lowest number of hand weeding hours, and produced the highest fruit yields. Therefore, decisions on what might be used on this crop should be based on weed pressure and soil type of the farming site and environmental factors, such as soil temperature and soil moisture after planting. Unfortunately, clomazone has not yet been registered in Chile for use in bell pepper and is the only broadleaf herbicide selective in POST applications; therefore, weed management should be based on selective PTI sprayings follow by hand- and mechanical-weeding practices.

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