Critical period of weed control in transplanted chilli pepper

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Summary

Field experiments were conducted from 1991 to 1993 to determine the critical period of weed control in chilli pepper. The maximum weed-infested period ranged between 0.7 and 3.2 weeks after transplanting (WAT) at a 5% yield loss level. To prevent losses in total and marketable yields, weeds should be removed 2.1 or 0.9 WAT respectively. The end of the critical period decreased as the predetermined yield loss level increased from 2.5% to 10%. The minimum weed-free period ranged between 6.7 and 15.3 WAT at a 5% yield loss level depending on crop yield category. The chilli pepper crop required an average of 12.2 weeks of weed-free maintenance to avoid losses above 5%. Using a 5% yield loss level, the duration of the critical period of weed control was 14 weeks in 1991 and 11.2 weeks in 1993, but was shortened to 5.1 weeks in 1992. The results suggest that weeds must be controlled during the first half of the crop's growing season in order to prevent yield losses.

Keywords: *Capsicum annuum*, competition, growth response curves, non-linear regression.

Introduction

Chilli pepper (*Capsicum annuum* L.) is an important horticultural crop in Mexico on account of the considerable earnings produced and employment generated. Based on world production of this crop, Mexico ranks third behind Turkey and Nigeria. Zacatecas, located in the north-central states of Mexico, ranks fourth in chilli pepper production in Mexico producing 64 000 t ha^{-1} in 1996 (Barreiro, 1998). According to pungency level, chilli peppers are classified as 'sweet' or 'hot'. In Mexico, the production is mainly dedicated to the production of 'hot' cultivars, such as Serrano, Jalapeno, Poblano and Mirasol. The cultivars Mirasol and Poblano are the most widely grown in Zacatecas.

In previous studies, Aguilar-Acosta (1975) determined that the main weeds infesting chilli pepper cultivars in the Zacatecas region are *Amaranthus palmeri* S Watson, *Bidens odorata* Cav., *Simsia amplexicaulis* (Cav.) Medic. and 11 other species of less importance. However, *B. odorata* is the dominant weed species, infesting 36–40% of fields. One of the major factors limiting local production is the high cost of labour required to control weeds. Growers commonly use mechanical and hand hoeing, applying from 3–10 cultivations throughout the growing season (Amador-Ramírez, 1991). Because chilli pepper production in Zacatecas has shown a dynamic development in recent years, information about timely weed control is required.

Growers assume that weed competition problems are solved by removing weeds at any time during the growing season (Zimdahl, 1980). An important contribution to management of the critical period for weed control in chilli pepper is the development of alternative weed management strategies (Weaver & Tan, 1987; Swanton & Weise, 1991). A weed management approach could be the use of pre-emergence herbicides and/or cultivations. The concept of critical period describes the early period of crop growth when weeds need to be controlled to prevent yield reduction (Zimdahl, 1980). The critical period for weed control is constituted by the overlap of two components: the minimum weed-free period and the maximum weed-infested period (Ghosheh *et al.*, 1996). The critical period for weed control has been determined for several field (Van Acker *et al.*, 1993; Woolley *et al.*, 1993) and vegetable crops (Roberts, 1976; Friesen, 1979; Weaver & Tan, 1987;

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Baziramakenga & Leroux, 1994). Although Liu *et al.* (1984) found that weeds should be removed within 24 d, but no later than 36 d, after transplanting to prevent yield losses in sweet peppers, Frank *et al.* (1992) reported that the mean weed interference period needed for a 10% reduction in fruit weight in bell pepper was 38.5 d. Weed interference for 37–42 d also resulted in a 10% reduction in fruit number in bell pepper (Frank *et al.*, 1992).

One of the main concerns is the usefulness of the concept of critical period of weed control for an integrated weed management (IWM) system approach. First of all, IWM is an integration of effective weed and crop management practices, such as the use of timely and appropriate cultivations and effective chemical methods in a crop production system (Shaw, 1982). Shaw (1982) stated that the objectives of IWM include the reduction of crop losses resulting from weeds, costs of weed control, labour requirements and tillage. Frequent cultivation and hand hoeing are required to produce the chilli pepper crop, indicating that the critical period concept is useful for IWM in stabilizing the number of cultivations or using pre-emergence herbicides with enough soil residual activity to control weeds during the critical period of weed control (Burnside *et al.*, 1998). The critical period of weed control concept has been evaluated on traditional cultivars under a conventional tillage system such as mouldboard ploughing (Van Acker *et al.*, 1993; Wilson, 1993). However, studies are actually incorporating the concept of critical period for weed control in glyphosate-resistant cultivars under a no-tillage system (Mulugeta & Boerboom, 2000; Swanton *et al.*, 2000). These authors identified the critical period for weed control in a no-tillage glyphosate-resistant soyabean (*Glycine max* (L.) Merr.) as the unifoliate to trifoliate growth stage. Two applications of glyphosate were necessary to provide season-long weed control and higher yields and gross returns. However, these researchers pointed out that growers, based on the principles of critical period of weed control in IWM, can make management decisions such as minimizing herbicide application by avoiding the second application when applying glyphosate at the unifoliate stage of soyabean. On the other hand, no trend relative to definition of treatments about increasing duration of weed-free and weed-infested periods in studies on critical period of weed control has been defined. To determine any critical period, this can be based on either phenological stages of genotypes, heat units (Mickelson & Harvey, 1999), or on periods of time (Chhokar & Balyan, 1999). For chilli pepper, the use of periods of time was preferred because information on crop phenological growth stages was not available. The understanding of the critical period of weed control during crop growth will allow growers to manage weeds in production fields effectively.

In the production region of Zacatecas, information on herbicides for weed control is limited, but the use of preplanted incorporated and/or post-emergence herbicides in chilli pepper in other regions is well documented (Baltazar *et al.*, 1984; Schroeder, 1992a, b). The possibility of introducing herbicides for controlling weeds as well as continuing to cultivate at various intervals in chilli pepper crops in Zacatecas justifies the necessity for determining the critical period for weed control. Such information will allow determination of the adequacy of weed management programmes. Therefore, the objectives of this study were to (1) determine the critical period of weed control in chilli pepper production in Zacatecas; (2) evaluate the interference of early emerging weeds with crop yields; and (3) evaluate the effect of late-emerging weeds on crop yields.

Materials and methods

Field experiments

Experiments were conducted at the Calera Agricultural Experiment Station near Zacatecas, Mexico, from 1991 to 1993 (22°54′ N latitude, 102°39′ W longitude, 2197 m asl). The plots were established on loamy soils consisting of 39% sand, 38% silt and 23% clay with a pH of 7.6 and an organic matter content of 2.6% in 1992, as well as 46.5% sand, 40% silt and 13.5% clay with an organic matter content of 1.8% in 1993. Unfortunately, there is no soil description for 1991. Cultural practices, such as mouldboard ploughing to a 25-cm depth, disking and land levelling, were applied in the spring. Fifty-day-old 'hot' chilli pepper seedlings, cultivar Mirasol, were hand-transplanted in rows spaced 76 cm apart at a population density of 65 000 plants ha^{-1}. Transplanting dates were 6 May 1991 and 1992 and 10 May 1993. Plot size was four rows each 7.5 m long, and plots were separated by two border rows. Water was applied by furrow irrigation to the plot area throughout the crop growing season. Fertilizer was band-applied 2 weeks after transplanting at a rate of 60 kg ha^{-1} nitrogen and 60 kg ha^{-1} phosphate.

The experimental design was a randomized complete block with four replicates. Two types of weed interference treatments were applied starting at crop transplanting. In order to evaluate the onset of the critical period of weed removal, plots were left weedy for 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24 and 26 weeks from crop transplanting (WAT). To determine the end of the critical period, plots were kept weed-free for 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24 and 26 weeks by periodic hand-hoeing. Weedy control and weed-free control treatments were included in the experiments.

Weed and crop measurements

Naturally occurring weed populations were used in all trials. Trials were conducted on different sites in successive years. Weed infestations were evaluated at the end of each treatment by classifying and counting weed plants in a 0.5 m × 1.0 m quadrat per plot. Above-ground weed fresh and dry weights were determined from this quadrat. Weed height was determined by measuring plants selected randomly according to the weed species dominating the weed community in each plot. Crop variables included yield, plant density and plant height. Total crop yield was divided into marketable and unmarketable yield by visual inspection of each fruit. Fruits showing a clean red colour with no spots were classified as marketable, whereas fruits showing pale red colour or white-spot discoloration were rejected. Enumeration of fruits per plot and category was done after classification. The two centre rows of each plot were harvested to determine crop yields, number of fruits and crop density. Number of fruits per plot was transformed to number of fruits per plant after dividing it by the number of plants per plot. Weed and crop measurements on a per plot basis were transformed to m^{-2}.

Statistical analysis

All data were subjected to ANOVA using PROC GLM (SAS, 1996). To determine a possible interaction effect, a combined analysis of variance using years as main plots and weed interference treatments as subplots was performed on the crop yield data. Because the ANOVA indicated a significant treatment by year interaction, the data were analysed separately for each year. Total yield, expressed as a percentage of the weed-free control as a function of time, was examined by non-linear least-squares regression using PROC NLIN (SAS, 1996). Gompertz and logistic equations were fitted to the yield data for increasing duration of weed-free and weed-infested periods respectively (Van Acker *et al.*, 1993; Woolley *et al.*, 1993). The Gompertz model used consisted of three parameters:

$$Y = \mathrm{A} * \exp[-\mathrm{B} * \exp(-\mathrm{K} * T)] \quad (1)$$

where Y is the estimated crop yield (% of weed-free crop yield), T is the time expressed in weeks after transplanting, A is the theoretical maximum yield, B is yield as time equals zero, and K represents the slope.

The relationship between increasing duration of weed interference and crop yield was fitted to the logistic model:

$$Y = \{[1/(\mathrm{D} * \exp(\mathrm{K} * T)) + \mathrm{F}] + [(\mathrm{F} - 1)/\mathrm{F}]\} * 100 \quad (2)$$

where Y is the predicted crop yield (% of weed-free crop yield), T is the duration in weeks of weed interference from crop transplanting, and D, K and F are constants.

The total number of chilli pepper fruits per plant as a function of time was also examined by non-linear regression using PROC NLIN (SAS, 1996). The Gompertz model was used to describe total fruits per plant as a function of the weed-free period. The fruit count per plant in response to weed interference was better described by the following model (Anonymous, 1994):

$$Y = A + B * \{1/[1 + \exp(-(T - \mathrm{D})/ - \mathrm{K})]\} \quad (3)$$

where Y is the estimated number of fruits per plant, T is the time expressed in weeks after transplanting, A is the lower asymptote of fruit number, B is the upper asymptote, and D and K are constants. The three models were fitted separately for each year and each weed infestation. The coefficient of determination R^2 was calculated as described by Vandepitte *et al.* (1995). To determine the critical period of weed interference, three yield loss levels of 2.5%, 5% and 10% were chosen arbitrarily. The onset and end of the critical period were determined by substituting the yield loss level in the logistic and Gompertz equations respectively.

Results and discussion

Weed and crop measurements

The weed community was composed of six and four species in 1992 and 1993 respectively (Table 1). Unfortunately, weed density data for 1991 were missed. In 1992, the major weed species were *S. amplexicaulis* and *A. palmeri* accounting for 72% and 16% of the total density, whereas the major weed species in 1993 were *A. palmeri*, *Galinsoga parviflora* Cav. and *B. odorata* accounting for 53%, 30% and 15% of the total density. *Bidens odorata* and *G. parviflora* were also present in 1992 but at a lower density than in 1993. Weed species such as *S. amplexicaulis*, *Helianthus petiolaris* Nutt. and *Eragrostis diffusa* (Buckl.) were present only in 1992.

Table 1 Weed composition and average density (plants m^{-2}) in unweeded controls measured 26 weeks after transplanting

Species	1992	1993
Total	150	80
Simsia amplexicaulis	108	–
Amaranthus palmeri	24	42
Helianthus petiolaris	6	–
Bidens odorata	6	12
Galinsoga parviflora	4	24
Eragrostis diffusa	2	–
Chenopodium album	–	2

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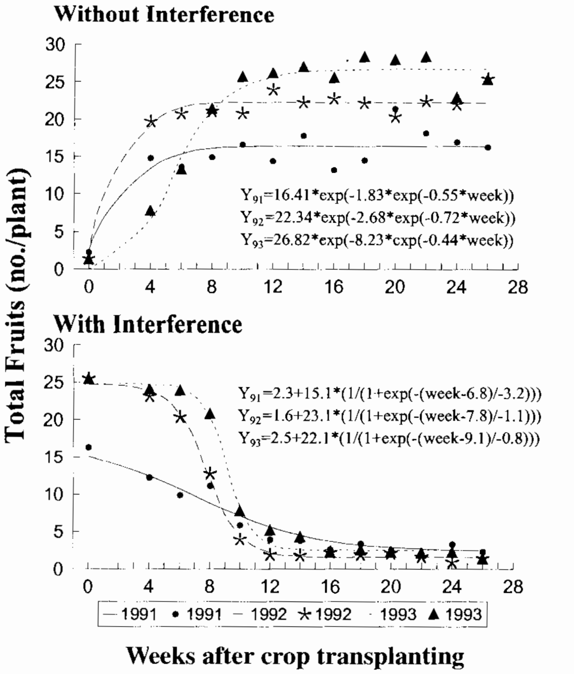

Fig. 1 Effect of weed interference treatments on the total number of fruits per plant of transplanted chilli pepper in 1991, 1992 and 1993. Increasing duration without weed interference as calculated by the Gompertz equation (1); increasing period with weed interference as calculated by the equation from TABLECURVE software (3).

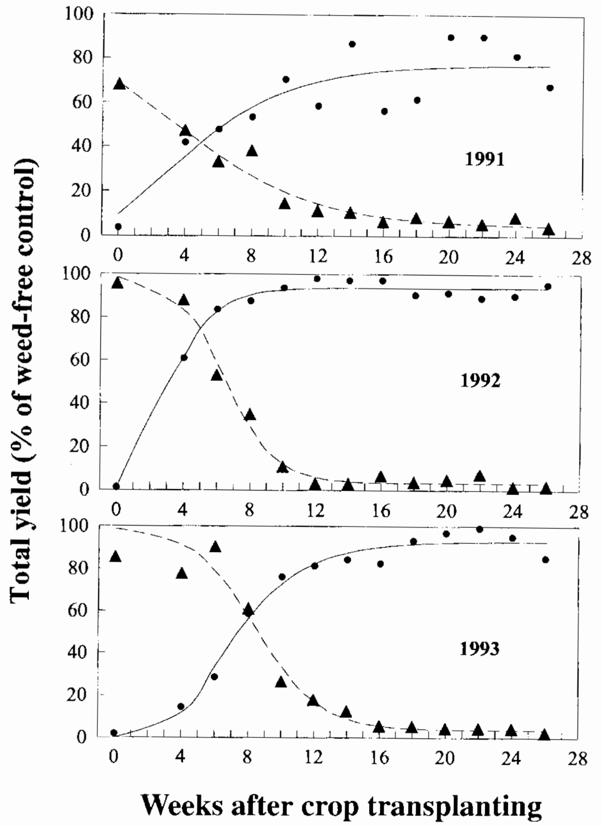

Fig. 2 Effect of weed interference treatments on total yield of transplanted chilli pepper in 1991, 1992 and 1993. Increasing duration of weed interference (triangles) as calculated by the logistic equation (2); increasing weed-free period (circles) as calculated by the Gompertz equation (1). Dots represent observed data.

by total and marketable categories were different in 1992, indicating that the non-marketable crop contributed to total yield more than the marketable crop. Remaining comparisons within years between total and marketable yields were not different (Table 3). The reason for the low R^2 from the relationship between marketable crop yield and the increasing weed-free period in 1991 compared with 1992 and 1993 is not apparent, as the parameter estimates were similar to other years (Table 3). In contrast, it is likely that the non-marketable crop yield has increased variability in the relationship between total crop yield and the increasing weed-free period in 1991.

The maximum predicted yield reductions, which are the D parameter estimate, occurred in 1992 and 1993 for total and marketable crop yield (Table 4). For total yield, these maximum yield reductions were related to significantly faster predicted yield rates. Although maximum predicted yield reduction parameters in 1992 and 1993 were similar for marketable yield, the predicted yield rate to achieve such a reduction was much faster in 1992 than in 1993 in response to the increased weed density that occurred in 1992. Differences in maximum predicted yield reduction parameters between total and marketable crop yield were estimated in 1992 and 1993 (Table 4). These differences were supported by the differences in predicted yield rates for those years. In 1993, the predicted yield rate quantified for increasing the weed-infested period was faster than that for increasing the weed-free period in total crop yield. Differences in parameter estimates of the response curves varied among years and between yield categories as a response to differences in weed species, weed density and environmental conditions (Kropff *et al.*, 1993).

The onset of the critical period increased in chilli pepper as the predetermined yield loss level increased from 2.5% to 10% (Table 5). The maximum weed-infested period ranged between 0.7 and 3.2 WAT at a 5% yield loss level. To prevent losses in total and marketable yields, weeds should be removed from chilli pepper fields at 2.1 or 0.9 WAT, respectively, based on the 3-year average for weed-infested periods. The onset of the critical period for total crop yield was earlier in 1991 compared with 1992 or 1993. This early onset of the critical period could be attributed to a higher weed density at the beginning of the growing season, resulting in a reduced total fruit number and reduced crop yield (Figs 1 and 2). Unfortunately, there were no data on weed density for 1991 to support the above

Table 3 Parameter estimates for the Gompertz equation* used to fit yield data for increasing weed-free period

Crop yield	Year	A	B	K	x	R^2
Total	1991	77.4 (± 6.41)	2.12 (± 1.165)	0.249 (± 0.1126)	3.0	0.38
	1992	93.5 (± 1.20)	4.88 (± 2.804)	0.611 (± 0.1352)	2.6	0.93
	1993	92.9 (± 3.16)	8.51 (± 3.937)	0.354 (± 0.0695)	6.1	0.84
Marketable	1991	85.9 (± 7.71)	2.33 (± 1.397)	0.244 (± 0.1158)	3.5	0.38
	1992	89.9 (± 1.94)	9.30 (± 16.029)	0.781 (± 0.4161)	2.9	0.82
	1993	95.9 (± 5.29)	16.14 (± 15.389)	0.389 (± 0.1251)	7.1	0.70

*Y = A × exp[−B × exp(−K × T)], where Y = total or marketable yield loss (%), T = duration of weed interference from crop transplanting (weeks), x = point of inflection (weeks); and A, B and K are constants.

Table 4 Parameter estimates for the logistic equation* used to fit yield data for increasing weed-infested period

Crop yield	Year	D	K	F	R^2
Total	1991	0.501 (± 0.0978)	0.238 (± 0.0387)	1.044 (± 0.0291)	0.78
	1992	0.017 (± 0.0079)	0.641 (± 0.0721)	1.033 (± 0.0153)	0.95
	1993	0.014 (± 0.0089)	0.512 (± 0.0783)	1.038 (± 0.0269)	0.89
Marketable	1991	0.432 (± 0.0932)	0.264 (± 0.0429)	1.029 (± 0.0275)	0.78
	1992	0.116 (± 0.0276)	0.436 (± 0.0427)	1.003 (± 0.0138)	0.94
	1993	0.127 (± 0.0414)	0.316 (± 0.0488)	1.001 (± 0.0301)	0.84

*Y = {[1/(D × exp(K × T) + F)] + [(F − 1)/F)]} × 100, where Y = total or marketable fruit yield (% of season-long weed-free control); T = duration of weed interference from crop transplanting (weeks); D, K and F are constants.

Table 5 The onset of the critical period in chilli pepper calculated from the logistic equations for three predetermined levels of crop yield loss

		Time for indicated percentage yield loss		
		2.5%	5.0%	10.0%
Crop yield	Year	WAT*		
Total	1991	0.4	0.7	1.3
	1992	1.5	2.3	3.3
	1993	2.2	3.2	4.5
	3-year average	1.4	2.1	3.0
Marketable	1991	0.3	0.7	1.3
	1992	0.5	0.9	1.7
	1993	0.7	1.2	2.2
	3-year average	0.5	0.9	1.7

*WAT, weeks after crop transplanting.

Table 6 The end of the critical period in chilli pepper calculated from the Gompertz equations for three predetermined levels of crop yield loss

		Time for indicated percentage yield loss		
		2.5%	5.0%	10.0%
Crop yield	Year	WAT*		
Total	1991	17.4	14.7	11.9
	1992	8.6	7.4	6.3
	1993	16.3	14.4	12.4
	3-year average	14.1	12.2	10.2
Marketable	1991	18.0	15.3	12.6
	1992	7.6	6.7	5.7
	1993	16.6	14.8	12.9
	3-year average	14.1	12.3	10.4

*WAT, weeks after crop transplanting.

conclusions. The end of the critical period decreased as the predetermined yield loss level increased from 2.5% to 10% (Table 6). The minimum weed-free period ranged between 6.7 and 15.3 WAT at a 5% yield loss level depending upon year of evaluation. Therefore, the chilli pepper crop requires an average of 12.2 weeks of weed-free maintenance to avoid losses above 5%.

Using a 5% yield loss level, the critical period for weed control was between 0.7 and 14.7, 2.3 and 7.4, and 3.2 and 14.4 WAT for total crop yield (Tables 5 and 6). At the same percentage yield loss level, the critical period for weed control was between 0.7 and 15.3, 0.9 and 6.7, and 1.2 and 14.8 WAT for marketable crop yield. The duration of the critical period of weed control was 14 weeks in 1991 and 11.2 weeks in 1993, but was shortened to 5.1 weeks in 1992. Ghosheh *et al.* (1996) pointed out that long critical periods are indicative of more competitive weeds or less competitive crops (Oliver, 1988). Woolley *et al.* (1993) found that the critical period of weed control might vary depending upon crop cultivars and weed pressure levels among other factors.

Practical implications

The development of any IWM system requires a knowledge of the behaviour of weeds in the agroecosystem, including possible effects on crop yields. The approach of the critical period of weed control is part of that knowledge that would allow the development of strategies for IWM. The results of this study suggest that weeds must be controlled during the first half of the chilli pepper growing season in order to prevent yield losses. The results of the experiments contribute to the development of an IWM system for cv. Mirasol in Zacatecas. The definition of the critical period of weed control supports the early suppression of weeds using pre-emergence herbicides or cultivation whose amount would depend on weed pressure. Data from this study provide a basis for producers of chilli pepper to make a decision with respect to timely weed control measures, regardless of methodology.

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