INTERFERENCE OF WEEDS ON GROWTH AND YIELD OF TRANSPLANTED DRY CHILE PEPPER

M. D. Amador-Ramírez[1¶]; R. Velásquez-Valle[2]; A. G. Bravo-Lozano[1]; R. Gutiérrez-Luna[1]

[1]Campo Experimental Zacatecas, Instituto Nacional de Investigaciónes Forestales y Agropecuarias. Apartado Postal 18. Calera V. R., Zacatecas, C. P. 98500. MÉXICO. Correo-e: amador.mario@inifap.gob.mx ([¶]Autor responsable).

[2]Campo Experimental Pabellón, Instituto Nacional de Investigaciónes Forestales y Agropecuarias. Apartado Postal 20. Pabellón de Arteaga, Aguascalientes, C. P. 20660. MÉXICO

ABSTRACT

To study the effect of weed interference on growth and yield of dry chile pepper, field experiments were carried out in different sites in 1998 and 1999. The experiment was established under a completely randomized complete block design with two types of weed interference treatments: plots with weeds and plots without weeds at different time intervals. We measured internode length, stem diameter, plant height and water-use efficiency as a response to time intervals of weed interference, while weed-crop ratio was evaluated based on how much did weed dry matter reduced yield of dry chile pepper. Except for the tight relationship observed between curves and internode lengthening data from 1999, internode length, stem diameter and plant height were always higher under conditions with a an increased period without weed interference when compared to weed interference in both years. For both years, internode length, stem diameter and plant height started decreasing after eight or more weeks of weed interference. In both years, an amount of at least 4 t ha^{-1} of weed dry matter for treatments with increasing periods of weed interference was enough to decrease crop yields up to 67 % in 1999 and 88 % in 1998, when compared to treatments with lower amounts of weed dry matter. Under conditions of increased periods without weed interference, water-use efficiency measured at any sampling time in 1999 was lower than that in 1998 during the growth cycle, due to a 35 % evapotranspiration water loss that occurred in 1999.

ADDITIONAL KEY WORDS: *Capsicum annuum*, competition, growth curves, dry matter, non-linear regression.

INTERFERENCIA DE MALEZAS EN EL CRECIMIENTO Y RENDIMIENTO DE CHILE SECO DE TRANSPLANTE

RESUMEN

Para estudiar el efecto de la interferencia de malezas en el crecimiento y rendimiento del cultivo de chile seco, se llevaron a cabo experimentos de campo en diferentes sitios durante 1998 y 1999. El experimento se estableció en un diseño de bloques completamente aleatorizado con dos tipos de tratamientos de interferencia de maleza: parcelas enhierbadas y parcelas mantenidas libres de maleza en diferentes intervalos de tiempo. Se midió el alargamiento de los entrenudos, el diámetro del tallo, la altura de la planta y la eficiencia en el uso del agua en respuesta a intervalos de tiempo de interferencia de maleza, mientras que la relación maleza-cultivo se evaluó basada en cuánto de la materia seca de la maleza redujo el rendimiento de chile seco. Excepto por la estrecha relación observada entre las curvas y los datos de la variable alargamiento de los entrenudos en 1999, el alargamiento de los entrenudos, el diámetro del tallo y la altura de la planta fueron siempre mayores en condiciones de un incrementado período sin interferencia de maleza que con interferencia en ambos años. En ambos años, la elongación de los entrenudos, el diámetro del tallo o la altura de la planta empezó a disminuir después de ocho semanas o más de interferencia de maleza. En ambos años, una materia seca de alrededor de 4 t·ha^{1} mostrada por aquellos tratamientos bajo incrementados períodos con interferencia de maleza fue suficiente para reducir los rendimientos de cultivo hasta en 67 % en 1999 y 88 % en 1998, en comparación a los tratamientos con las más bajas cantidades de materia seca de maleza. En condiciones de incrementada duración sin interferencia de maleza, la eficiencia en el uso del agua del cultivo medida en cualquier época de muestreo en 1999 fue menor que en 1998 a través del ciclo del crecimiento, atribuyéndosele al 35 % de pérdida del agua por evapotranspiración ocurrida en 1999.

PALABRAS CLAVE ADICIONALES: *Capsicum annuum*, competición, curvas de crecimiento, materia seca, regresión no-lineal.

Recibido: 5 de noviembre, 2003
Aceptado: 28 de julio, 2004

INTRODUCTION

Dry chilli pepper (*Capsicum annuum*) is among the most widely cultivated chilli peppers in Zacatecas, México. A total of 228, 600 t of dry chilli pepper were produced in Mexico in 2002 and Zacatecas contributed with 26 % to the total production (SAGARPA, 2002). In Zacatecas, dry chilli pepper production system is stratified where up to 92 % of production units have 10 ha or less, while production unites with 30 ha or more represented 10 % of the total dry chilli surface (Reyes-Rivas *et al.*, 2000). Reyes-Rivas *et al.* (2002) observed a trend for some Zacatecas counties to cultivate certain dry chilli pepper genotypes in response to grower preferences and influences from gatherers rather than to agro-ecological characteristics among production areas or size of the production units. Dry chilli pepper genotypes more cultivated in Zacatecas were 'Mirasol-Guajillo', 'Puya', 'Ancho', 'Pasilla', and 'Mulato' with 55, 26, 12, 6, and 1 %, respectively.

In previous studies, Aguilar-Acosta (1975) and Galindo-González *et al*. (2002) determined that the main weeds infesting chilli pepper fields in the Zacatecas region are *Bidens odorata* Cav. (aceitilla), *Amaranthus palmeri* S. Watson (quelite), *Simsia amplexicaulis* (Cav.) Medic (lampote), weed grasses, and 14 other species of less importance. Much of the weed interference is related with the weed growing characteristics since all these main weeds grow larger than the crop does. Whereas *A. palmeri* grows as large as 1.5 or 2.0 m tall (Agundis and Rodríguez, 1978; Rowland *et al.*, 1999), *S. amplexicaulis* grows from 0.10 to 2.5 m (Villegas, 1979) and *Bidens* spp. grows from 0.6 to 1.5 m tall depending on beggarticks species (Mitich, 1999), implying an interference mainly for light.

The water use efficiency approach of crops can be defined as the ratio of that produced grain yield or dry matter to unit volume of total evaporation or to total evapotranspiration (Tanner and Sinclair, 1983). Several factors such as weed infestation or the lack of crop vigour caused by disease, insect attack and/or poor nutrition determine crop water use efficiency. To maximize crop water use efficiency, it is necessary to promote maximal growth and to conserve water by minimizing losses through evaporation and transpiration by weeds (FAO, 1997). Amador-Ramírez (1993, 1995) estimated reductions in the efficiency in producing dry matter up to 52 % or grain yield up to 90 % per unit of evapotranspired water, as weeds were allowed to compete throughout the maize growing season in comparison to those crop plants free of weed interference under climatological conditions of Zacatecas.

The critical periods for weed control in chilli pepper varies depending on crop genotype classes. To prevent yield losses in sweet peppers, weeds should be removed either within 6 weeks but no later than 9 weeks after transplanting (Liu *et al*., 1984) or 9.6 weeks for a 10 % reduction in fruit weight in bell pepper (Frank *et al*., 1992). However, dry chilli pepper required an average of 12.2 weeks of weed-free maintenance to avoid losses above 5 % (Amador-Ramírez, 2002). Based on this information, appropriate weed control measures should be undertaken. In Zacatecas, weed control in chilli pepper fields is achieved by applying from 3 to 12 cultivations and hand hoeing as required, while information on herbicides for weed control is limited. Mechanical and hand hoeing weed control accounted for about 27 % of the annual production costs of chilli pepper (Goyal, 1983).

Yield is a final expression closely related with growth and development of the plant. Because crop yields have an impact in the gross profit margin, the response to weed interference from diverse crops is usually measured in terms of yield losses. However, growth and development of crop plants are also affected either from the emergence or transplanting by weed interference. Therefore, the objective of this study was to determine the effects produced by weeds emerged either early or lately on growth and yield of transplanted chilli pepper plants.

MATERIALS AND METHODS

Experiments were conducted at the Calera Agricultural Experimental Station near Zacatecas, Mexico in 1998 and 1999 (22° 54' N latitude, 102°39' W longitude, 2197 m of altitude). 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 1998, as well as 46.5 % sand, 40 % silt and 13.5 % clay with an organic matter content of 1.8 % in 1999. Cultural practices such as moldboard plowing to a 25 cm depth, disking, and land leveling were applied in the spring in both years. Fifty-day old hot chilli pepper seedlings, cultivar Mirasol, were hand-transplanted in rows spaced 76 cm apart with a distance between plants of 31 cm, amounting a population of 42,000 plants·ha^{-1}. Transplanting dates were May 6, 1998 and May 10, 1999. Plot size was four rows 7.5 m long and plots were separated by two border rows. Water was applied by furrow irrigation to the plot area throughout the chilli pepper growing season. In both years, the first three irrigation events were applied 3, 10, and 18 d after planting, but the application time of remaining irrigations varied within and between years. Fertilizer was banded two weeks after transplanting at an only rate of 60 kg·ha^{-1} of nitrogen and 60 kg·ha^{-1} of phosphate.

The experiment consisted of two set of treatments established on a randomized complete block design with four replications. A set of treatments consisted of leaving weedy for 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, and 26 weeks after chilli pepper transplanting (WAT). In other set of treatments, plots were kept weed free for 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, and 26 weeks by hand-hoeing twice a week. Weedy control and weed-free control treatments were included in the experiments.

Weed and crop measurements

Naturally occurring weed populations were utilized in all trials. Trials were conducted on two different sites in successive two years (1998, 1999). Weed infestations were evaluated at the end of each treatment by classifying and counting weed plants in a 0.5 x 1.0 m randomized quadrant per plot. Aboveground weed dry matter from this quadrant was determined by placing weed plants within paper bags in an oven for 72 h. Chilli pepper variables included yield, internode elongation, stem diameter, plant height, and water use efficiency. The two center rows of each plot were harvested to determine total crop yields. Internodes from the middle-third of three chilli pepper plants randomly selected were measured at each replication. Stem diameter 5.0 cm top from the base of three crop plants at each replication was estimated with a vernier micrometer. Plant height from three crop plants also randomly selected was determined at each replicate. These samples of three crop plants were based on 47 plants per plot of 11.4 m^2.

Soil water content was determined gravimetrically from soil cores obtained at biweekly intervals in 30-cm increments to a depth of 60 cm, collecting one sample per plot. Soil sampling started 60 d after crop transplanting. Soil cores were dried in an oven at 100 C for 48 h. Soil water content was determined by the equation [(Wet Weight – Dry Weight)/Dry Weight]x100. Evapotranspiration from the chilli pepper crop was calculated as the difference in volumetric soil moisture between the two sampling times plus the precipitation between the two sampling dates. Water-use efficiency was defined as kilograms of fruit yield per millimeter of seasonal evapotranspiration.

STATISTICAL ANALYSIS

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 chilli pepper yield and growth parameter data. Because the ANOVA indicated a significant treatment by year interaction, all data were analyzed separately for each year too. Crop internode elongation, stem diameter, and plant height data as a function of time were examined by nonlinear least-squares regression using PROC NLIN (SAS, 1996). Gompertz equations [1] explained the response of growth parameters to increasing duration without weed interference and increasing period with weed interference (Woolley *et al*., 1993; Van Acker *et al*., 1993). The Gompertz model used consisted of three parameters:

$$Y=A\cdot \exp(-B\cdot \exp(-K\cdot T)) \qquad [1]$$

where Y is the estimated chilli pepper growth variables, T is the time expressed in weeks after transplanting, A is the theoretical maximum chilli pepper growth variables, B is chilli growth variables as time equals zero, K represents the slope, and exp represents the exponential response of the variables.

Total yield as a function of weed dry matter was also examined by nonlinear least-squares regression. Exponential equations [2] were fit to the yield data for increasing duration of weed-free and weed-infested periods:

$$Y=A\cdot \exp(-B\cdot WDM) \qquad [2]$$

where Y is the estimated chilli pepper yield, WDM is the weed dry matter occurred at each increasing period with or without weed interference, A is the chilli pepper yield as weed dry matter equals zero, B represents the slope, and exp represents the exponential response of the variable.

Crop water-use efficiency (WUE) in response to the weed-free period was described by the Gompertz model. Water-use efficiency in response to weed interference was better described by the following model (Anonymous, 1994):

$$WUE=A+(-B*(1/(1+\exp(-(T-D)/K)))) \qquad [3]$$

where WUE is the estimated crop WUE, T is the time expressed in weeks after transplanting, A is the upper asymptote of WUE, B is the lower 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).

RESULTS

Amaranthus palmeri S. Watson was the most prominent weed species occurred in treatments with increasing periods of weed interference in 1998, while in 1999 the density of this species was similar to *Galinsoga parviflora* Cav. and *Eragrostis diffusa* (Buckl.) (Table 1). In both years, *G. parviflora*, *Bidens odorata* Cav. and *E. diffusa* were also important because they emerged throughout the entire growing seasons. Densities of *B. odorata* were always lower than those densities of *A. palmeri* and *G. parviflora* in both years. *Simsia amplexicaulis* (Cav) Medic. became important only in 1998, while this species in 1999 was absent in some sampling dates or its density was so low enough to be included only as minor species.

In 1998, *G. parviflora* and *S. amplexicaulis* were constantly present throughout the chilli pepper growing season in treatments with increasing weed-free periods in comparison to remaining major weeds (Table 2). In contrast, major weed species showed an interrupted emergence from 18 WAP to the end in 1999. Densities of *B. odorata* were not constant in 1998, whereas this species in addition to *S. amplexicaulis* were absent in 1999. On the other hand, *Malva parviflora* was present only in 1999.

In general, densities of major weed species were much lower in treatments with increasing weed-free periods than in treatments with increasing periods of weed interference indicating how important is the timely weed control (Tables 1 and 2). Differences between years in weed composition and density can be attributed to the use of different experimental sites and previous management practices.

Growth variables

Except for the close relationship observed between curves and data from internode elongation variable in 1999, crop internode elongation, stem diameter, and plant height were always higher at conditions of increasing duration without weed interference than those with weed interference in both years (Figure 1). In both years, the response of all crop variables to increasing periods either of weed interference or without it during the first six weeks was similar. However, internode elongation, stem diameter, or plant height started to decrease after eight weeks or longer of weed interference. About a 50 % reduction in chilli pepper stem diameter caused by the increasing period of weed interference was constantly observed in both years in comparison to the crop stem diameter without interference, while the response of the other variables for weed interference was not constant between years.

Based on the R^2 coefficients, the Gompertz models in 1998 explained between 48 and 94 % of the variability

TABLE 1. Densities (plants·0.5 m^{-2}) of major weeds in treatments with increasing periods of weed interference in 1998 and 1999

	Weeks after crop transplanting											
Species	**4**	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**	**22**	**24**	**26**
1998												
Bidens odorata	2	8	7	8	12	33	18	10	10	11	3	3
Amaranthus palmeri	13	29	60	131	167	127	137	94	53	26	12	12
Galinsoga parviflora	15	41	25	42	20	39	33	38	31	19	8	2
Simsia amplexicaulis	0	1	15	20	58	38	27	27	17	57	48	54
Eragrostis difussa	2	0	8	10	6	10	8	10	9	1	0	1
Other species	0	5	2	9	7	6	9	10	8	5	4	3
1999												
Bidens odorata	2	7	4	14	7	1	2	3	5	9	10	6
Amaranthus palmeri	20	40	51	28	13	21	30	11	13	36	15	21
Galinsoga parviflora	20	41	21	48	19	25	34	21	27	23	17	12
Ergrostis difussa	2	26	70	33	44	21	23	21	14	5	13	0
Other species	1	7	13	9	9	6	5	7	4	1	1	1

TABLE 2. Densities (plants·0.5 m^{-2}) of major weeds in treatments with increasing weed-free periods measured at harvest in 1998 and 1999

	Weeks after crop transplanting											
Species	**4**	**6**	**8**	**10**	**12**	**14**	**16**	**18**	**20**	**22**	**24**	**26**
1998												
Bidens odorata	0	1	2	3	0	0	0	1	0	1	0	0
Amaranthus palmeri	7	4	1	1	1	0	0	0	0	0	0	1
Galinsoga parviflora	3	5	11	13	10	8	7	4	6	12	6	5
Simsia amplexicaulis	6	4	4	4	3	1	3	1	2	1	2	3
Eragrostis difussa	1	1	1	2	3	2	1	1	1	0	1	1
Other species	1	1	2	0	0	0	0	0	0	0	0	0
1999												
Bidens odorata	0	1	0	0	0	0	0	0	0	0	0	0
Amaranthus palmeri	12	10	2	3	3	2	2	0	0	0	0	0
Galinsoga parviflora	4	11	8	6	6	6	7	1	0	1	0	1
Eragrostis difussa	0	1	1	0	0	0	1	0	0	0	1	1
Other species	2	13	4	8	13	14	11	4	9	2	5	8

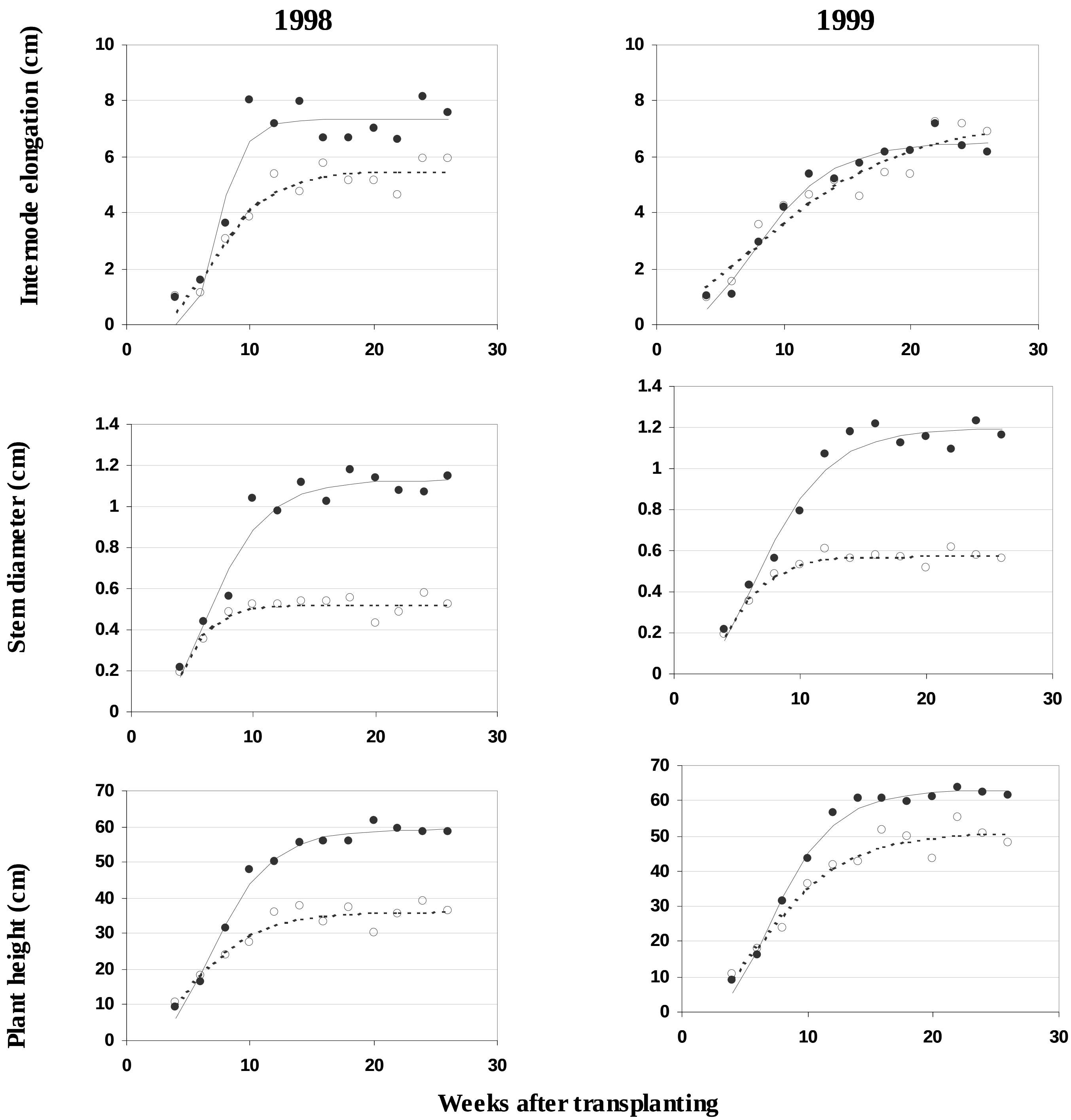

FIGURE 1. Chilli pepper growth variables in response to increasing duration without weed interference (closed symbol, solid line) and increasing period with weed interference (open symbol, dotted line) as calculated by the Gompertz equation in 1998 and 1999.

for internode elongation, stem diameter, and plant height data; the fit was always lower under conditions of increasing weed-infested than at increasing weed-free periods (Table 3). The predicted cumulative internode elongation, which is the A coefficient, from chilli pepper plants grown under increasing weed-infested periods was reduced 25 % in comparison to those grown at increasing periods of weed-free competition. Reductions of 55 % for cumulative stem diameter and 39 % for cumulative plant height of chilli pepper were also observed as a response to increasing periods of weed interference. The average internode elongation rate in 1998, which is the K coefficient, was significantly reduced in response to increasing periods of weed competition (Table 3). In contrast, the average rate for crop stem diameter was increased as a response to increasing weed-infested periods whereas no effect was observed in average plant height rate by weed presence. Rates of the maximum internode elongation (*w*) and the maximum plant

TABLE 3. Coefficient estimates for the Gompertz equation[z] used to fit internode elongation, stem diameter, and plant height data for increasing weed-free (WF) and increasing weed-infested (WI) periods in 1998.

Growth parameter	Condition	A	B	K	*w*	*x*	R^2
Internode elongation	WF	7.3 (0.14)	137.4 (106.97)	0.7 (0.11)	1.9	6.9	0.75
	WI	5.5 (0.15)	10.6 (4.14)	0.4 (0.05)	0.7	6.7	0.66
Stem diameter	WF	1.1 (0.02)	7.7 (1.71)	0.3 (0.03)	0.1	5.9	0.81
	WI	0.5 (0.01)	10.3 (5.50)	0.5 (0.11)	0.1	4.1	0.48
Plant height	WF	59.2 (0.58)	8.7 (1.11)	0.3 (0.02)	7.4	6.4	0.94
	WI	36.2 (0.84)	4.5 (1.24)	0.3 (0.05)	4.2	4.8	0.63

[z] $Y=A\cdot\text{EXP}(-B\cdot\text{EXP}(-K\cdot T))$, *Y*=growth variables, T=duration of weed interference from chilli pepper transplanting (weeks), *w*=maximum rate, *x*=point of inflection (weeks), and *A, B,* and *K* = constants. Values in parenthesis are standard errors of the estimate.

height were reduced about 63 and 43 % when chilli pepper plants were exposed to increasing periods of weed interference, respectively. On the other hand, the maximum stem diameter rate of chilli pepper plants exposed either to weed-free or weed-infested periods was similar. The inflection time (*x*), which is the time in weeks when the maximum rates of the different crop growth variables occurred, was usually earlier at conditions of increasing weed-infested periods.

In 1999, the Gompertz models through the R^2 coefficients explained between 53 and 93 % of the variability for internode elongation, stem diameter, and plant height data; as in 1998, the fit was always lower under conditions of increasing weed-infested than at increasing weed-free periods (Table 4). The predicted cumulative internode elongation, which is the A coefficient, from chilli pepper plants grown under increasing weed-infested periods was reduced 12 % in comparison to those grown at increasing periods of weed-free competition. Reductions of 50 % for cumulative stem diameter and 19 % for cumulative plant height of chilli pepper were also observed as a response to increasing periods of weed interference.

In contrast to the finding of 1998, the average and maximum internode elongation rates in 1999 were significantly increased in response to the higher weed density observed in plots with treatments consisted of increasing weed-infested periods, compared with the weed density in plots with increasing weed-free periods (Tables 3 and 4). It is possible that weeds have competed with chilli pepper plants mainly for light inducing the etiolation phenomenon (Rojas-Garcidueñas, 1972). On the other hand, the average rate for crop stem diameter was increased as a response to increasing weed-infested periods whereas no effect was observed in average plant height rate by weed presence. Maximum plant height rate was reduced about 38 % when chilli pepper plants were exposed to increasing periods of weed interference, whereas the maximum stem diameter rate exposed either to weed-free or weed-infested periods was similar. The inflection time was slightly earlier at conditions of increasing weed-infested periods.

Weed Dry Matter-Crop Yield Relationship

The relationship weed dry matter-crop yield was better described by exponential models; these models were a consistent reflection of how weed biomass influenced chilli pepper yield at both years (Figure 2). Dry matter of weeds growing in transplanted chilli pepper was 1.5-fold and 0.5-fold lower in 1998 than in 1999 at conditions of increasing duration without weed interference and increasing periods with weed interference, respectively. In both years, a weed dry matter of about 4.0 $t\cdot ha^{-1}$ showed by those treatments under increasing periods with weed interference was enough to reduce crop yields up to 67 % in 1999 and 88 %

TABLE 4. Coefficient estimates for the Gompertz equation[z] used to fit internode elongation, stem diameter, and plant height data for increasing weed-free (WF) and increasing weed-infested (WI) periods in 1999.

Growth variable	Condition	A	B	K	*w*	*x*	R^2
Internode elongation	WF	7.4 (0.38)	3.0 (0.40)	0.1 (0.02)	0.4	7.6	0.78
	WI	6.5 (0.19)	7.3 (2.00)	0.3 (0.04)	0.7	7.3	0.73
Stem diameter	WF	1.2 (0.02)	6.5 (1.37)	0.3 (0.03)	0.1	6.3	0.80
	WI	0.6 (0.01)	7.0 (2.90)	0.5 (0.08)	0.1	4.2	0.53
Plant height	WF	63.0 (0.70)	9.5 (1.38)	0.3 (0.20)	7.8	6.7	0.93
	WI	51.1 (1.72)	4.7 (1.30)	0.3 (0.04)	4.8	6.1	0.62

[z] $Y=A\cdot\text{EXP}(-B\cdot\text{EXP}(-K\cdot T))$, *Y*=growth variables, T=duration of weed interference from chilli pepper transplanting (weeks), *w*=maximum rate, *x*=point of inflection (weeks), and *A, B,* and *K* = constants. Values in parenthesis are standard errors of the estimate.

in 1998, in comparison to the treatment with the lowest weed dry matter. In 1998, a weed dry matter approximately of 2.0 t·ha^{-1}, showed by treatments under increasing duration without weed interference at harvest, reduced crop yield up to 15 %, whereas in 1999 about 4.0 t·ha^{-1} reduced crop yield up to 41 %, in comparison to the treatment with the lowest weed dry matter.

Based on coefficients of determination of 0.51 and 0.65, dry matter of weeds growing in chilli pepper crop at harvest was a less precise indicator of crop yield loss than was at increasing periods of weed interference where the coefficients of determination were 0.85 and 0.87 for 1998 and 1999, respectively (Figure 2). The regression coefficient for dry matter of weeds at increasing duration without weed interference conditions varied from -0.084 in 1998 to –0.15 in 1999, whereas at increasing periods with weed interference varied from –0.45 to –0.29 for 1998 and 1999, respectively, indicating that weed populations allowed to grow firstly are more aggressive in terms of yield reduction than those grown lately in the crop season.

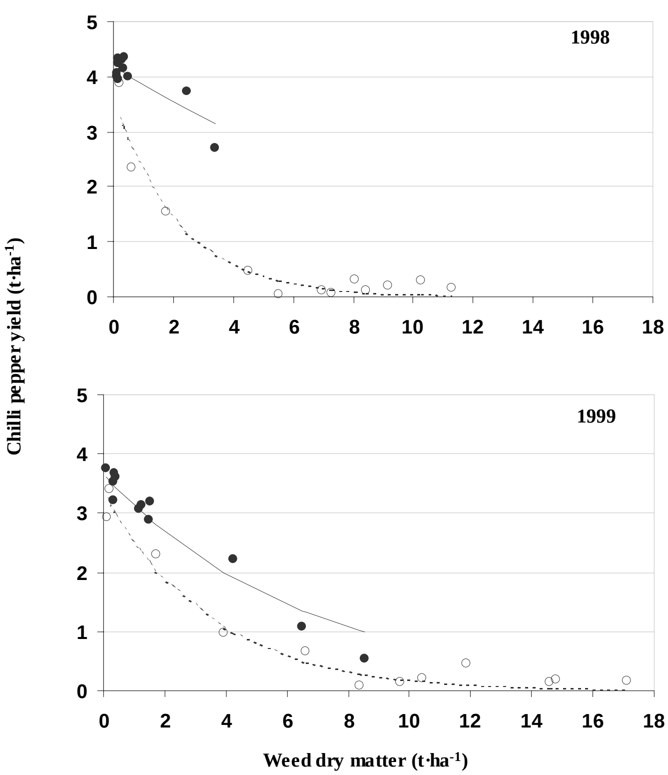

FIGURE 2. Transplanted chilli pepper yield (Y) in response to weed dry matter relative to increasing duration without weed interference (solid symbol, solid line) and increasing period with weed interference (open symbol, dashed line) as calculated by an exponential model. Chilli pepper yields exposed to increasing duration without weed interference were described by the equations Y_{1998}= 4.2·exp(-0.084·Weed Dry Matter), R^2=0.51 and Y_{1999}= 3.6·exp(-0.15·Weed Dry Matter), R^2=0.65. Chilli pepper yields exposed to increasing periods with weed interference were described by the equations: Y_{1998}=3.5·exp(-0.45·Weed Dry Matter), R^2=0.85 and Y_{1999}= 3.3·exp(-0.29·Weed Dry Matter), R^2=0.87.

Water Use Efficiency

Yields of transplanted chilli pepper as a function of evapotranspired water were more affected by increasing weed-infested periods than by increasing duration without weed interference (Figure 3a). At increasing duration without weed interference, the efficiency in crop water use (WUE) measured at any sampling time in 1999 was lower than in 1998 throughout the growing season, attributable to the 35 % higher crop water loss by evapotranspiration occurred in 1999. The Gompertz models accounted for 93 and 84 % of the variability in measured WUE in 1998 and 1999, respectively. The maximum and the rate of WUE predicted by the Gompertz model were reduced about 44 % in 1999 in comparison with those WUE coefficients from 1998. Treatments with weed-free periods of 6 and 10 weeks after crop transplanting were enough to show a similar WUE than those treatments with longer weed-free periods (Figure 3a).

At increasing periods with weed interference (Figure 3b), exponential models accounted for 95 and 90 % of the

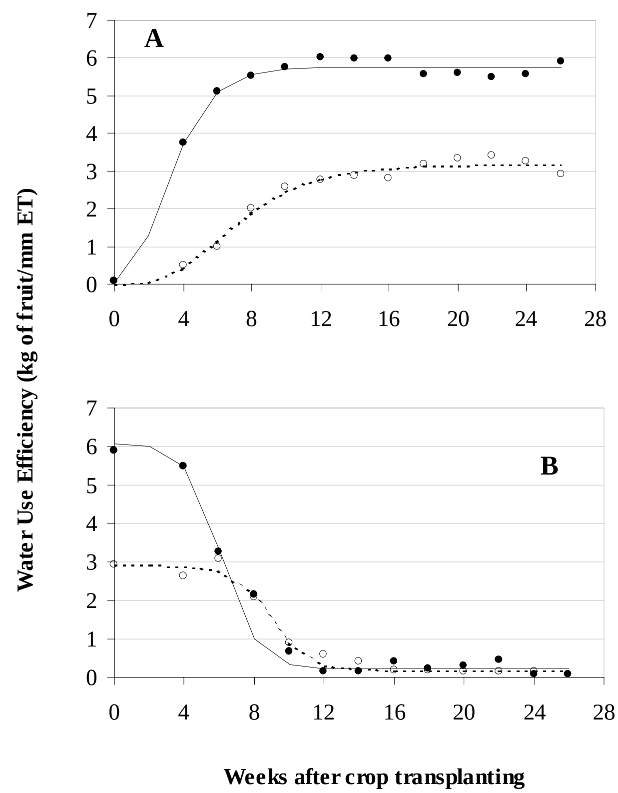

FIGURE 3. Water use efficiency (WUE) of transplanted chilli pepper in response to increasing duration without weed interference (A) and increasing period with weed interference (B) in 1998 (closed symbol, solid line) and 1999 (open symbol, dashed line). Water use efficiencies of chilli pepper exposed to increasing duration without weed interference were described by the Gompertz equations: WUE_{1998}= 5.8·exp(-5.3·exp(-0.62·Time), R^2=0.93 and WUE_{1999}= 3.2·exp(-8.3·exp(-0.35·Time), R^2=0.84. The water use efficiencies of chilli pepper exposed to increasing period with weed interference were described by the models: WUE_{1998}= 6.1+(-5.9*(1/(1+exp(-(Time-6.53)/1.50)))), R^2=0.95 and WUE_{1999}= 2.9+(-2.7*(1/(1+exp(-(Time-8.99)/1.11)))), R^2=0.90.

variability in measured WUE in 1998 and 1999, respectively. The predicted maximum WUE was reduced about 52 % in 1999 in comparison to 1998, and this difference extended to week 6, after which WUE started to be similar between years. Treatments with weed-infested periods for 10 weeks or longer after crop transplanting showed a similar WUE than those treatments with shorter weed-free periods. Whereas in 1998 WUE linearly decreased 94 % from week 4 to week 10, a decrement of 89 % in WUE occurred from week 6 to week 12 in 1999.

DISCUSSION

Based on the crop growth response, transplanted chilli pepper was clearly affected by weed interference. It has been determined that some crops become taller due to the enlargement of longitudinal axis or etiolation phenomena (Rojas-Garcidueñas, 1972; Morales-Payan *et al.*, 2003) with no induction of leaf extension (Ray, 1975) when leaves of plants are exposed to barriers that block light absorption or to weed competition mainly for light than crop plants with no competition. In addition to the etiolation phenomena, plants of chilli pepper were rachitic and shorter than crop plants free of weed interference as was observed in sunflowers (Johnson, 1971), cotton (Askew and Wilcut, 2002a; Askew and Wilcut 2002b), and siratro (Wong and Wilson, 1980) indicating that crop growth response to weed interference is dependent on crop and weed type and density.

Dry weight of weeds allowed to grow in plots with increasing weed-infested periods in the chilli pepper was a more precise indicator of crop yield reduction than was the weed dry weight accumulated in treatments with increasing weed-free periods. This indication is given by the coefficients of determination in addition to the close relationship between observed and predicted data of chilli pepper yield. It has been previously determined that crop yields tend to be reduced as weed dry weight increases accounting for an inverse relationship. This crop yield compared to weed biomass fit a linear (Thurlow and Buchanan, 1972; Rowland *et al.*, 1999; Askew and Wilcut, 2002a; Askew and Wilcut 2002b), quadratic (Johnson and Mullinix, 1999), or exponential (Clewis *et al*., 2001) model as was observed in this study. Differences between years in the crop yield-weed dry biomass relationship could be explained by changes in crop yield potential and weed dry biomass accumulation as stated by Clewis *et al.* (2001).

The water use efficiency, expressed as the kilograms of fruits produced per unit volume of evapotranspired water, of transplanted chilli pepper was other element affected by weed presence. Similar findings on the suppression of water use efficiency, expressed as the kilograms of dry matter or seed yield per unit volume of evapotranspired water, of two corn varieties by weed interference were observed by Amador-Ramírez (1993, 1995). Water loss by evapotranspiration influenced on the response of corn varieties as well as it influenced on the response of chilli pepper between years. Several factors such as weed infestation or the lack of crop vigour caused by disease, insect attack and/or poor nutrition determine crop water use efficiency. To maximize crop water use efficiency, it is necessary to promote maximal growth and to conserve water, which is achieved by minimizing losses through runoff, seepage, evaporation and transpiration by weeds (FAO, 1997). Weeds can use large amounts of stored water and rainfall that enters the soil during the crop growth resulting in competing with the crop and reducing its water use efficiency (NSW, 1999). Therefore, improvements in water use efficiency can be achieved through correcting a variety of limitations to crop growth, including weed presence. In our study, efficiency in chilli pepper water use was reduced as weeds became established. The theoretical basis for the association between crop water use and weeds is that the presence of weeds becomes a limiting factor due to the water loss by transpiration caused by the great amount of weeds per unit surface that use to be present in crop fields.

The chilli pepper life cycle from transplanting to maturity has duration of 26 weeks requiring a period of up to 12 weeks of weed-free maintenance to avoid losses above 5 % (Amador-Ramírez, 2002). This long time of crop growth and development allows to weeds become well established resulting in reductions of crop growth and yield, which can be avoided by reducing the time of weed establishment. Given the lack of effective registered herbicides for transplanted chilli pepper, mechanical and hand hoeing control are the only options to manage weeds and minimize yield loss (Amador-Ramírez, 1991).

CONCLUSIONS

Growth, yield and water use efficiency of transplanted dry chilli pepper crop were closely related to timely weed control. Crop growth parameters such as internode elongation, stem diameter, and height of plants exposed to either weed-free periods or increasing periods of weed interference were similar until week 8 after transplanting, after which they decreased as weed interference period increased.

Although weeds, that were present in treatments with increasing weed interference periods, produced between 11 and 17 t·ha^{-1} of dry matter, about 4.0 t·ha^{-1} were enough to reduce chilli pepper yields. Control measures applied under the context of increasing weed interference period or increasing weed-free period, where the production of weed dry matter was approximately of 4 t·ha^{-1}, should be avoided.

The efficiency of dry chilli pepper in terms of kilograms of crop fruit produced per mm of evapotranspired water in response to increasing periods with weed interference was affected from the week 8 to the end of the experiment. On the other hand, differences between years for the crop water use efficiency in response to increasing periods without weed interference was due to the higher evapotranspired water loss occurred in 1999.

ACKNOWLEDGEMENTS

We want to thank to the Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, for supporting this project. Appreciation is extended to Manuel de Haro Pinedo for his technical assistance.

LITERATURE CITED

AGUILAR-ACOSTA, S. 1975. Reconocimiento zonal de malezas en el cultivo de chile. Informe de Investigación Agrícola Ciclo 1975. CIANE-INIA. Campo Experimental Zacatecas. México.

AGUNDIS M., O.; RODRÍGUEZ J., C. 1978. Maleza del algodonero en la Comarca Lagunera. Instituto Nacional de Investigaciones Agrícolas. Folleto Misceláneo No. 40. 105 p.

AMADOR-RAMÍREZ, M. D. 1991. Diagnostico de malezas en chile (*Capsicum annuum*) en Zacatecas. Memorias XII Congreso Nacional de la Ciencia de la Maleza. Acapulco, Guerrero, México. p. 103.

AMADOR-RAMÍREZ, M. D. 1993. Efecto de la maleza en el crecimiento del maíz. Terra 11: 106-114.

AMADOR-RAMÍREZ, M. D. 1995. Interferencia de malezas en maíz en Zacatecas. Agric. Téc. Méx. 21: 17-28.

AMADOR-RAMÍREZ, M. D. 2002. Critical period of weed control in transplanted chilli pepper. Weed Res. 42: 203-209.

ANONYMOUS. 1994. TableCurve 2D. User's Manual. Jandel Scientific, Inc. San Rafael, CA, USA. 400 p.

ASKEW, SH. D.; WILCUT, J. W. 2002a. Ladysthumb interference and seed production in cotton. Weed Sci. 50: 326-332.

ASKEW, SH. D.; WILCUT, J. W. 2002b. Pennsylvania smartweed interference and achene production in cotton. Weed Sci. 50: 350-356.

CLEWIS, S. B.; ASKEW, SH. D.; WILCUT, J. W. 2001. Common ragweed interference in peanut. Weed Sci. 49: 768-772.

FAO. 1997. Small-scale irrigation for arid zones: Principles and options. Food and Agricultural Organization. http://www.fao.org/docrep/W3094E/w3094e04.htm.

FRANK, J. R.; SCHWARTZ Jr., P. H.; POTTS, W. E. 1992. Modeling the effect of weed interference periods and insects on bell pepper (*Capsicum annuum*). Weed Sci. 40: 308-312.

GALINDO-GONZÁLEZ, G.; LÓPEZ-MENDIOLA, C.; CABAÑAS-CRUZ, B.; PÉREZ-TRUJILLO, H.; ROBLES-MARTÍNEZ, A. 2002. Caracterización de productores de chile en el altiplano de Zacatecas. Instituto Nacional de Investigaciones Agrícolas, Pecuarias y Forestales. Campo Experimental Zacatecas. Folleto Científico No. 5. 102 p.

GOYAL, M. R. 1983. Labor-input requirements for experimental production of summer peppers under drip irrigation. J. Agric. Univ. Puerto Rico. 67: 22-27.

JOHNSON, B. J. 1971. Effect of weed competition on sunflowers. Weed Sci. 19: 378-380.

JOHNSON III, W. C.; MULLINIX Jr., B. J. 1999. *Cyperus esculentus* interference in *Cucumis sativus*. Weed Sci. 47: 327-331.

LIU, L. C.; GONZALEZ-IBANEZ, J.; GOYAL, M. R. 1984. Weed competition in transplanted sweet peppers. Proceedings of the Caribbean Food Crops Society 20: 198-199.

MITICH, L. W. 1994. Intriguing World of Weeds: Beggarticks. Weed Technol. 8: 172-175.

MORALES-PAYAN, J. P.; STALL, W. M.; SHILLING, D. G.; CHARUDATTAN, R.; DUSKY, J. A.; BEWICK, T. A. 2003. Above- and belowground interference of purple and yellow nutsedge (*Cyperus* spp.) with tomato. Weed Sci. 51: 181-185.

NSW, 1999. SOILpak program for dryland farmers on the red soil of Central West NSW. New South Wales Department of Agriculture. Minister for Agriculture. UK. http://www. agric. nsw. gov. au /reader /6865.

RAY, P. M. 1975. La Planta Viviente. Editorial Continental. D. F., México. 272 p.

REYES-RIVAS, E.; SALINAS-GONZÁLEZ, H.; BRAVO-LOZANO, A. G.; PADILLA-BERNAL, L. E. 2000. Tecnología de producción de chile seco en el Estado de Zacatecas, México. Terra 19: 83-88.

ROJAS-GARCIDUEÑAS, M. 1972. Fisiología Vegetal Aplicada. McGraw-Hill. D.F., México.

ROWLAND, M. W.; MURRAY, D. S.; VERHALEN, L. M. 1999. Full-season Palmer amaranth (*Amaranthus palmeri*) interference with cotton (*Gossypium hirsutum*). Weed Sci. 47: 305-309.

SAS. 1996. SAS/STAT User's Guide. Version 6.12. Statistical Analysis Systems Institute, Carey, N.C., USA. 705 p.

SAGARPA, 2002. Avance de Siembras y Cosechas. Servicio de Información y Estadística Agroalimentaria y Pesquera. Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación. D. F., México. http//www. siea. sagarpa.gob.mx/indexgiras2.html

TANNER, C. B.; SINCLAIR, T. R. 1983. Efficient water use in crop production: Research or Re-Search? pp. 1-27. *In*: Limitations to Efficient Water Use in Crop Production. TAYLOR, H. M.; JORDON, W. R.; SINCLAIR, T. R. (eds.). ASA, CSSA, and SSSA. Madison, WI. USA.

THURLOW, D. L.; BUCHANAN, G. A. 1972. Competition of sicklepod with soybean. Weed Sci. 20: 379-384.

VANDEPITTE, V.; QUATAERT, P.; DE RORE, H.; VERSTRAETE, W. 1995. Evaluation of the Gompertz function to model survival of bacteria introduced into soils. Soil Biology & Biochemistry 27: 365-372.

VILLEGAS Y DE GANTE, M. 1979. Malezas de la Cuenca de México. Instituto de Ecología A.C. Publicación No. 5. D.F., México. 140 p.

WONG, C. C.; WILSON, J. R. 1980. Effects of shading on the growth and nitrogen content of green panic and siratro in pure and mixed swards defoliated at two frequencies. Aust. J. Agric. Res. 31: 269-285.