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Effect of in-row cultivation, herbicides, and dry bean canopy on weed seedling emergence

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Field experiments were conducted in 1996 and 1997 to evaluate the effect of EPTC (*S*-ethyl dipropyl carbamothioate) plus ethalfluralin at 2.4 plus 0.83 kg ai ha^{-1}, rotary hoeing, in-row cultivation, rotary hoeing plus in-row cultivation, and dry bean canopy on weed seedling emergence. Cumulative weed emergence in 1996 and 1997 was similar in cropped and noncropped areas. Herbicides were more effective than mechanical cultivation in reducing weed emergence 91% in 1996 and 88% in 1997. Weed emergence was similar in both rotary hoed area and cultivated area in 1996 but weed emergence was 44% lower in rotary hoed plots than in cultivated plots in 1997. The Gompertz equation did not adequately predict weed seedling emergence in the untreated control and with in-row cultivation in 1996. Initial weed seedling emergence was observed at about 120 growing degree-days with 3 to 9% cumulative emergence among treatments. In 1997, the Gompertz equation adequately described weed seedling emergence in plots with or without disturbed soil. Weed emergence was first observed at 80 growing degree-days with 6 to 16% cumulative emergence among treatments. Predicted percent weed emergence closely approximated observed emergence in 1996 and 1997. Rotary hoeing plus in-row cultivation reduced maximum percent emergence rate 37% on an average. The greater maximum percent emergence rate obtained with in-row cultivation suggests that this treatment increased weed seedling emergence in 1997. On average, weed seedling emergence in the untreated check was lower in cropped areas than in noncropped areas, implying a competitive effect by the dry bean crop. Although weed seedling emergence occurred throughout the growing season, more weed seedlings emerged in June and early July than in late July and August.

Nomenclature: EPTC (*S*-ethyl dipropyl carbamothioate); ethalfluralin; redroot pigweed, *Amaranthus retroflexus* L. AMARE; common lambsquarters, *Chenopodium album* L. CHEAL; hairy nightshade, *Solanum sarrachoides* Sendt. SOLSA; wild proso millet, *Panicum miliaceum* L. PANMI; dry bean, *Phaseolus vulgaris* cv; Great Northern 'Beryl'.

Key words: Nonlinear regression, preplant incorporated herbicides, rotary hoeing, undisturbed soil, thermal time units.

Weed seedlings emerging with crops or soon thereafter are a major problem because they interfere more with crop growth and development than later emerging weeds (Knezevic et al. 1997; Schweizer et al. 1998). Weeds emerging anytime during crop development will compete with the crop for resources; but the longer the period of interference, the greater the effect on the crop. Weed management could be simplified if all weeds emerged at the same time. However, the emergence of weed seedlings is an intermittent process with the greatest number appearing during the summer (Popay and Roberts 1970a).

Crop presence may affect weed seedling emergence by inducing changes in the soil microclimate around the weed seed and consequently reducing the effect of weeds on the crop. Soil climate changes induced by crop presence would include reduction in the amount and quality of light, CO_2 concentration in the soil, and interference of heat transfer. These changes reduce weed seed germination and consequently emergence. Effects of crop presence on weeds include the delay of weed seedling emergence (Fidanza et al. 1996) and the reduction in weed density (Benech-Arnold and Sanchez 1995). Weeds that emerge in areas of lower crop density usually become bigger because of less competition from crop plants (Andersson and Bengtsson 1992). Under conditions of dense crop cover, suppression of weed germination and seedling emergence occurs because the crop canopy interferes with the exposure of weed seeds to light, which stimulates germination (Popay and Roberts 1970a). Crop competitiveness, however, varies with crop varieties and weed pressure (Limon-Ortega et al. 1998; Oryokot et al. 1997; Santos et al. 1997). In the case of dry bean (*Phaseolus vulgaris*), Wortmann (1993) found that large leaf size, greater leaf area index, and greater crop growth rate suppressed weeds.

To suppress weed emergence, crop competitiveness should be used in conjunction with other weed control methods, such as herbicides or mechanical weeding. Herbicides such as EPTC (*S*-ethyl dipropyl carbamothioate) and ethalfluralin are applied and incorporated into the soil before dry bean planting to prevent weed seedling emergence. However, because of a growing concern for the contamination of soils, crop productivity, and water quality, dry bean producers are interested in using mechanical practices to replace or complement herbicides (VanGessel et al. 1998).

Between-row cultivation controls most weeds located away from crop plants, but one of the concerns of dry bean producers is the growth of weeds located in the crop row. Options for in-row weed control include the use of rotary hoeing and in-row cultivation. Timely weed control during the early dry bean growth stages helps to suppress weeds, but there is little information about the effect of rotary hoeing and in-row cultivation on weed seedling emergence. Mulugeta and Stoltenberg (1997b) found that secondary tillage from rotary hoeing or in-row cultivation in a no-tillage corn (*Zea mays*) and soybean [*Glycine max* (L.) Merr.] cropping system increased weed seedling emergence. Exposure of seeds to light, greater soil aeration, and greater loss of volatile inhibitors from the soil are consequences of cultivation, which may increase the weed seedling emergence (Egley 1986). If weed seeds are buried at a depth of 2.5 cm or more, then germination and emergence are usually reduced because of the lack of light, increasing CO_2 concentration, and decreasing oxygen concentration (Popay and Roberts 1970b).

Effective weed management can usually be achieved with cultural, mechanical, and chemical methods. However, the ability to predict weed emergence throughout the crop growing season would help develop effective weed control strategies and would result in limiting the unnecessary use of weed control methods. Thermal time (TT) has been used to estimate or predict the effect of temperature on crop and weed development (Forcella and Banken 1996; Vitta and Leguizamon 1991; Wilen et al. 1996). TT models for predicting emergence of smooth crabgrass (*Digitaria ischaemum* Schreber) in Kentucky bluegrass (*Poa pratensis* L.) (Fidanza et al. 1996), yellow nutsedge (*Cyperus esculentus* L.) in cotton (*Gossipium hirsutum*) (Wilen et al. 1996), redroot pigweed, common lambsquarters, and giant foxtail (*Setaria faberi* Herrm.) in corn (Forcella et al. 1997), and eastern black nightsahde (*Solanum ptycanthum* Dun.), powell amaranth (*Amaranthus powellii* S. Wats.), green foxtail [*Setaria viridis* (L.) Beauv.], and common lambsquarters in tomato (*Lycopersicum esculentum* L.) (Weaver et al. 1988) have been determined. However, TT models for predicting weed seedling emergence in dry beans are not available.

In an effort to predict weed seedling emergence, researchers have used mechanistic and empirical models. Empirical models were developed by using multiple linear and nonlinear regressions to examine the effect of thermal time, rainfall, soil strength, or temperature on weed emergence. Empirical models once developed and validated can be used to predict weed emergence or incorporate weed emergence into subroutines of mechanistic models. Asymptotic growth functions such as the monomolecular, the logistic, and the Gompertz models have been used to predict seed germination and cumulative weed emergence (Bahler et al. 1989; Fidanza et al. 1996; Tipton 1984). Another method of developing cumulative emergence models is log transformation of the independent variable. Under this method, accumulated thermal time or accumulated rainfall has been used to predict the emergence of common lambsquarters, giant foxtail, and redroot pigweed (Mulugeta and Stoltenberg 1997a, 1997b).

The suppression of weed seedlings emerging in corn and soybean rows has been studied. However, the effect of a less competitive crop such as dry bean and effects of rotary hoeing, in-row cultivation, and herbicides on weed seedling emergence are not known. The use of thermal time accumulation may help to predict in-row weed emergence and when the greatest number of weeds will emerge in dry bean and thus allow for the timely application of mechanical weed control. Therefore, the objectives of this study were to (1) evaluate the effect of dry bean canopy, herbicides, and in-row cultivation on weed seedling emergence, and (2) describe cumulative weed seedling emergence under the influence of dry bean, rotary hoeing, and in-row cultivation using the thermal time as a descriptive tool.

Materials and Methods

Field experiments were conducted during 1996 and 1997 at the University of Nebraska Panhandle Research and Extension Center near Scottsbluff, NE (41°56′N latitude, 103°41′W longitude, 1,220 m above sea level). The plots were established on a Tripp sandy loam soil (course-silty, mixed mesic Typic Haplustoll) with a pH of 7.8 and organic matter of 0.9%. Great Northern 'Beryl' dry edible bean variety was planted on June 3, 1996 and June 12, 1997 under irrigated conditions in rows spaced 76-cm apart. Bean population was 210,000 plants ha^{-1} at emergence. Water was applied by sprinkler irrigation to the plot area throughout the dry bean growing season. The first irrigation was 10 d after planting (DAP) in 1996 and 17 DAP in 1997, followed by weekly irrigations.

A randomized complete block design with a split plot arrangement of treatments and four replicates was used for the experiment. Whole plots were crop presence or crop absence. Whole plot size was 20 rows wide by 20 m long. Subplots consisted of four weed control treatments plus an untreated check. Subplot size was four rows wide by 10 m long. Weed control treatments were based on the use of herbicides, rotary hoeing, in-row cultivation, and the combination of rotary hoeing plus in-row cultivation. The herbicide treatment consisted of a mixture of EPTC plus ethalfluralin applied at 2.4 plus 0.83 kg ai ha^{-1}, respectively. Before dry bean planting, herbicides were applied with a tractor-mounted sprayer equipped with six flat-fan nozzles.[1] The herbicide mixture was incorporated with a power-driven rotary tiller 5 to 8 cm deep. The rotary hoeing was done at the cotyledon stage of crop growth in 1996 and 6 d later in 1997 relative to the time in 1996. In-row cultivation[2] was done at the unifoliate and at the fourth trifoliate leaf stages of crop growth. A fourth treatment consisted of combining rotary hoeing and in-row cultivation at the above mentioned crop stages. The in-row cultivator was equipped with spiders in front, torsion bar weeders in the middle, and spinners in the rear. The front spiders were adjusted to move soil away from the crop row. Torsion bar weeders were 15 to 18 cm apart at the narrowest point and adjusted to 2.5 cm deep. Spinners were adjusted so that they moved through the crop row at a 30° angle to the rows. Rotary hoeing or in-row cultivation was always done after weed count, and the effect of these activities was evaluated by assessing weed emergence the following week. Rotary hoe or in-row cultivator was used at cotyledon stage of weed growth, and weeds were not allowed to grow beyond because they were removed at each sampling time.

Four permanent quadrats 18 cm wide by 1.5 m long were established in the two center rows of each plot. Each row had two quadrats, 2 m apart. After applying the weed control treatments and to facilitate weed counts at specified sites within plots, adjacent areas to the permanent quadrats were kept weed free for the entire growing season. Weed seedlings were identified, counted, and removed at weekly intervals throughout the growing season. Weed species included common lambsquarters, redroot pigweed, hairy nightshade, common purslane (*Portulaca oleracea* L.), wild proso millet, and green foxtail. All data for the cumulative seedling emergence from the field were converted to a square meter basis.

Soil temperature was recorded daily at 7.5 cm depth in 1996 and at 5.0 cm depth in 1997. Soil temperature in 1996 was obtained from an automated weather station, whereas in 1997 soil temperature was obtained by installing maximum–minimum soil thermometers. A maximum–minimum soil thermometer was placed in each treatment of the first replication planted with dry bean as well as in each treatment of the fourth replication under bare soil after crop planting. To obtain the maximum and minimum temperatures for the same day, readings were taken between 1800 and 2000 h every day. Soil temperature data were converted to soil thermal time units by the equation:

$$\mathrm{TT} = \sum_{i=1}^{n} [(\mathrm{T}_{\max} + \mathrm{T}_{\min})/2] \cdot \mathrm{T}_{\mathrm{b}} \qquad [1]$$

$$\text{If } (\mathrm{T}_{\max} + \mathrm{T}_{\min})/2 < \mathrm{T}_{\mathrm{base}}$$

$$\text{then } (\mathrm{T}_{\max} + \mathrm{T}_{\min})/2 = \mathrm{T}_{\mathrm{base}}$$

$$\text{If } (\mathrm{T}_{\max} + \mathrm{T}_{\min})/2 > \mathrm{T}_{\mathrm{upper}}$$

$$\text{then } (\mathrm{T}_{\max} + \mathrm{T}_{\min})/2 = \mathrm{T}_{\mathrm{upper}}$$

where $T_{\max}$ is the maximum temperature, $T_{\min}$ is the minimum temperature, T_{b} is the base temperature (10 C at 5 cm depth), T_{upper} is upper temperature (30 C at 5 cm depth), and n is the number of days elapsed since planting dates. Because weed development has not been described by growing degree-days, base and upper temperatures used in the calculations of thermal time units were those utilized in calculations of growing degree-days for corn development.

To determine the soil water status, soil water content (%) was measured at weekly intervals. Soil cores obtained with a 7.6-cm diameter bulb planter at intervals from 0 to 2.5 cm and from 2.5 to 5.0 cm deep were sampled from two replicates and dried in an oven at 100 C for 24 h. Soil water content was determined by the equation:

$$[(\text{wet weight} - \text{dry weight})/\text{dry weight}] \times 100. \qquad [2]$$

Analysis of variance was performed using PROC GLM (SAS 1996) to test the significance among treatments for cumulative weed seedling emergence. Weed emergence at each sampling date as affected by treatments was also analyzed by the General Linear Model procedure to test significance among treatments. Orthogonal contrasts were constructed for comparing weed seedling emergence in whole plots as well as among subplots. At the whole plot level, a comparison between cropped and noncropped areas was examined. At the subplot level, comparisons among weed control treatments were calculated. Such contrasts were constructed to compare cumulative weed emergence over the season or weed emergence at each sampling date.

Weed seedling emergence in percent (the dependent variable) as a function of thermal time (independent variable) was examined by nonlinear least squares regression using PROC NLIN (SAS 1996). Weed seedling emergence from the 2-yr was converted by a linear transformation to percentage emergence, taking the highest weed cumulative emergence for each year as 100% emergence (Harris et al. 1998; Oryokot et al. 1997). Cumulative emergence of 558 seedlings m^{-2} and 420 seedlings m^{-2} at the end of season were recorded in 1996 and 1997, respectively.

Because of the nonlinear response (lack of normality) of the dependent variable, the relationship between weed seedling emergence (WSE) and TT was fit to the Gompertz function. The Gompertz function consisted of three parameters,

$$\mathrm{WSE} = A \times \exp(-B \times \exp(-K \times \mathrm{TT})) \qquad [3]$$

where WSE represents the predicted cumulative percent emergence, TT is cumulative thermal time based on maximum and minimum soil temperatures measured at 5 or 7.5 cm depth, and A, B, and K are coefficients; A is the theoretical maximum percent emergence, B is the initial emergence as thermal time equals zero, and K represents the rate of cumulative percent emergence. Gompertz equation parameters such as inflection time, maximum emergence rate, and cumulative percent emergence were also used in evaluating weed seedling emergence. The relationship between weed seedling emergence and thermal time was also fit to the logistic function, but the results were not taken into account because the analysis with this asymptotic function showed higher residual mean squares than the Gompertz function.

The PROC NLIN procedure was run on each replicate of each crop growth–treatment control combination producing four estimates for each parameter for each equation. The herbicide treatment was omitted from the regression analysis because of the low weed emergence, which was the result of high level of weed seedling control. Adequacy of nonlinear least squares regression equations was based on the mean square error. Analysis of variance was performed using PROC GLM (SAS 1996) to test the significance of the K parameter, inflection time, cumulative emergence at inflection time, and maximum emergence rate at inflection time, as affected by treatments. The PROC TTEST procedure was run on each sampling date to compare weed seedling emergence in cropped and noncropped areas for each treatment.

Results and Discussion

Rainfall and irrigation were greater in 1997 than 1996 and resulted in higher soil moisture (Table 1). In the 1996 experiment, there was no rainfall in 5 and 7 wk. As a result, 52 and 6 mm of irrigation water was applied in 5 and 7 wk, respectively. Only 6 mm of water was applied in 7 wk because rainfall in 6 wk was 38 mm. On the basis of the similar weed seedling emergence without taking into account crop canopy effect, differences in soil temperature of about 2 C between 1996 and 1997 did not influence weed emergence at the end of the season.

Pattern of Seedling Emergence

Cumulative weed emergence at the end of season in cropped plots was similar to weed emergence in noncropped

Table 1. Rainfall, irrigation, soil temperature, and soil water each week after planting during the experiments in 1996 and 1997.

	Rainfall		Irrigation		Soil temperature		Soil water	
Week	1996	1997	1996	1997	1996	1997	1996	1997
	mm				C		%	
1	10	5	0	0	21.0	21.9	—	17.7
2	2	14	5	0	24.1	24.8	12.3	17.0
3	6	1	0	41	26.3	24.7	10.3	19.0
4	3	2	15	21	25.4	23.3	10.3	17.2
5	0	1	52	29	25.5	23.8	11.9	18.3
6	38	4	0	6	23.7	25.6	12.3	18.2
7	0	46	6	46	25.6	23.9	10.7	20.4
8	3	15	12	0	25.7	22.4	10.2	17.8
9	20	26	14	0	23.5	20.2	12.3	19.4
Total	82	114	104	144				
Average					24.5	23.4	11.3	18.3

areas in 1996 and 1997 (Table 2). Chemical control plots accumulated 91% fewer weed seedlings m^{-2} in 1996 and 88% fewer in 1997 than rotary hoeing and in-row cultivation plots. Cumulative weed emergence was similar for rotary hoeing and in-row cultivation in 1996, but emergence of weeds in rotary hoed plots was 44% lower than with in-row cultivation in 1997. No difference between years in weed species was determined, rather similar weed emergence for rotary hoeing and in-row cultivation in 1996 was related to the effectiveness of in-row cultivation. However, rotary hoeing was more effective in suppressing cumulative weed emergence than in-row cultivation in 1997; this is because of a delay of 6 d relative to the use of rotary hoeing in 1996 that allowed it to be more effective.

Weed emergence was 83% less in cropped plots compared with noncropped plots because of the late emergence of weeds in noncropped plots (Table 3). No reduction in weed emergence because of the presence of dry beans was observed at other sampling dates indicating that dry bean did not influence weed seedling emergence. Mechanical treatments reduced cumulative weed seedling emergence 55% compared with the untreated check only on June 26 indicating that mechanical weed control did not stimulate weed emergence compared with no soil disturbance at other sampling times (Table 3). Herbicides suppressed weed emergence more than mechanical treatments throughout the growing season because weeds often emerged after mechanical weed control. In-row cultivation reduced weed emergence by 92% compared with rotary hoeing on June 26 and by 87% on July 9, but not at other sampling times. Effectiveness of in-row cultivation at these sampling times was related to the use of the in-row cultivator on June 21 and July 8. The second cultivation suppressed weeds until July 16, and then additional weed emergence occurred.

Weed emergence in noncropped and cropped plots was similar until August 1, 1997, then late season emergence of weed seedlings was greater in cropped plots (Table 4). In response to in-row cultivation, mechanical cultivation reduced weed emergence 49% on average on July 3 and 11 but then increased emergence on July 25 compared with the untreated check. Mulugeta and Stoltenberg (1997a) found that a close relationship between secondary soil disturbance and seasonal variation in the amount of rainfall influenced weed emergence compared with nondisturbed soil. Herbicides reduced emergence of weeds throughout the growing season more than mechanical treatments. Effective weed suppression by EPTC plus ethalfluralin agreed with previous findings of Burnside et al. (1994) and VanGessel et al. (1998) who estimated up to 99% reduction of weed density. Rotary hoeing in comparison with in-row cultivation reduced weed emergence by 70% on June 27, 1997 but not on July 3 because of the effect of in-row cultivation done on July 1. Weed emergence in in-row cultivated plots was different from rotary hoed plots at other sampling times as a result of the in-row cultivation done on July 9, as well as to late weed emergence at remaining sampling times. Late flushes of weeds after in-row cultivation have been reported by Forcella et al. (1993). Swanton and Murphy (1996) noted that the primary role of cultivation is to manage early emerging weeds.

Parameter Analysis

No crop by mechanical treatment interaction was determined in each Gompertz parameters analyzed each year. Therefore data presented in Table 5 were placed on crossed mechanical treatments or crossed cropped and noncropped areas basis. However, the use of results from individual mechanical treatments was necessary to explain crossed responses. The theoretical maximum emergence, which is the A coefficient estimate of the Gompertz equation, closely approximated cumulative observed emergence in 1996 and 1997 because of the numerical analysis conducted with de-

Table 2. Total weed seedling emergence under dry bean presence and absence as affected by herbicides, rotary hoeing, and in-row cultivation.

Contrasts[a]	1996		1997	
	Seedlings m^{-2}	Probability	Seedlings m^{-2}	Probability
Main Plots				
Crop vs. No Crop	146 vs. 175	0.549	155 vs. 151	0.773
Subplots				
UC vs. Others	212 vs. 148	0.140	171 vs. 149	0.114
Chem.[b] vs. Mech.	17 vs. 192	0.001	23 vs. 191	0.001
RH[c] vs. IR[d]	281 vs. 212	0.335	142 vs. 255	0.012

[a] Abbreviations: UC, untreated check; RH, rotary hoe; IR, in-row cultivation; Chem., chemical control; Mech., mechanical control.

[b] Herbicides were sprayed at preplanting time and then incorporated.

[c] Rotary hoe was used at crop cotyledon stage.

[d] In-row cultivation was made at unifoliate and fourth trifoliate stage.

TABLE 3. Weed seedling emergence as affected by dry bean presence, herbicides, rotary hoeing, and in-row cultivation in 1996.

Sampling date[b]	Contrasts[a]							
	Crop vs. no crop	Probability	UC vs. mech.	Probability	Chem. vs. mech.	Probability	RH vs. IR	Probability
	Seedlings m^{-2}		Seedlings m^{-2}		Seedlings m^{-2}		Seedlings m^{-2}	
6/11	37 vs. 34	0.95	31 vs. 46	0.20	8 vs. 46	0.001	63 vs. 48	0.63
6/26	18 vs. 23	0.59	42 vs. 19	0.02	2 vs. 19	0.04	52 vs. 4	0.004
7/2	5 vs. 4	0.36	7 vs. 5	0.41	1 vs. 5	0.004	9 vs. 5	0.09
7/9	7 vs. 23	0.06	28 vs. 15	0.13	0 vs. 15	0.02	39 vs. 5	0.002
7/23	4 vs. 24	0.002	15 vs. 19	0.67	0 vs. 20	0.002	16 vs. 30	0.59
8/6	6 vs. 5	0.28	7 vs. 6	0.76	0 vs. 6	0.002	5 vs. 12	0.04

[a] Abbreviations: UC, untreated check; Chem., chemical control; Mech., mechanical control; RH, rotary hoeing; IR, in-row cultivation.

[b] Bean planting occurred on June 3; rotary hoeing was done on June 11 just after the weed count; in-row cultivation was done on June 21 and July 8.

pendent data (data not presented). The analysis of variance performed on the cumulative emergence rate, which is the K coefficient, showed that the treatment differences by crop presence in 1996 and by mechanical weeding in 1997 were significant (Table 5). The difference between cropped and noncropped plots is related to the effect of in-row cultivation. In 1996, in-row cultivation alone and combined with rotary hoeing contributed to the treatments in cropped areas having the highest cumulative emergence rates, whereas in 1997 the effect of in-row cultivation was similar to the other treatments (data not presented). Whereas in 1996, the *K* cumulative emergence rate for the different treatments was similar, rotary hoeing plus in-row cultivation reduced cumulative emergence more than the untreated check in 1997 (Table 5). The untreated check had a *K* cumulative emergence rate similar to the emergence rate from rotary hoeing or in-row cultivation in 1997.

The Gompertz inflection time, which is the time in TT units when the maximum emergence rate occurred, was not modified by dry bean presence in either year and mechanical weeding in 1996 (Table 5). In 1997, the combination of rotary hoeing plus in-row cultivation showed a delayed Gompertz inflection time, indicating that this treatment destroyed more emerging weed seedlings than the other treatments, and the time required to reach the point when the maximum emergence rate occurred was greater. The Gompertz cumulative emergence, the cumulative weed emergence in percent occurring at the time of the inflection, was not affected by dry bean presence in both years, indicating crop interference was ineffective at that inflection time (Table 5). In 1996, rotary hoeing plus in-row cultivation reduced cumulative weed emergence 77% compared with rotary hoeing alone. However, rotary hoeing reduced weed emergence 47% compared with in-row cultivation in 1997.

The effect of crop presence on Gompertz maximum emergence rate, an estimate of the highest rate of seedling emergence at the moment when the inflection occurred, was different between years (Table 5). In 1996, maximum emergence rate was estimated in cropped plots, whereas in 1997 maximum emergence rate was similar in cropped and noncropped areas. The maximum emergence rate in cropped and noncropped areas occurred at 191 TT in 1996 and 148 TT in 1997, which were reached 2 wk after planting. The emergence of hairy nightshade in cropped areas and wild proso millet in noncropped areas at 15 DAP in 1996 and 1997 was greater than at other time period and therefore increased the maximum emergence rate (data not presented). In-row cultivation had the highest maximum emergence rate in 1997, suggesting this increased weed emergence until the inflection time (Table 5). A possible explanation for this response is that in-row cultivation improved soil aeration, exposed seeds to light, and increased the loss of volatile inhibitors from the soil, as reported by Egley (1986). On the basis of responses of maximum emergence rate to individual applications of rotary hoeing or in-row cultivation (Table 5), it is possible that rotary hoeing reduces maximum emergence rate more than in-row cultivation.

On the basis of the deviation of weed emergence predicted from the dependent observed data, the Gompertz equation overestimated cumulative weed seedling emergence

TABLE 4. Weed seedling emergence as a affected by dry bean presence, herbicides, rotary hoeing, and in-row cultivation in 1997.

Sampling date[2]	Contrasts[a]							
	Crop vs. no crop	Probability	UC vs. mech.	Probability	Chem. vs. mech.	Probability	RH vs. IR	Probability
	Seedlings m^{-2}		Seedlings m^{-2}		Seedlings m^{-2}		Seedlings m^{-2}	
6/20	48 vs. 52	0.79	47 vs. 67	0.17	0 vs. 67	0.001	50 vs. 88	0.02
6/27	26 vs. 35	0.12	42 vs. 36	0.19	2 vs. 36	0.001	20 vs. 67	0.002
7/3	14 vs. 20	0.21	32 vs. 17	0.003	3 vs. 17	0.001	20 vs. 20	0.98
7/11	7 vs. 10	0.16	16 vs. 8	0.001	1 vs. 8	0.001	11 vs. 7	0.04
7/25	17 vs. 12	0.79	9 vs. 21	0.05	2 vs. 21	0.001	9 vs. 29	0.02
8/1	10 vs. 4	0.005	6 vs. 9	0.48	3 vs. 9	0.01	4 vs. 11	0.01
8/14	7 vs. 3	0.003	2 vs. 6	0.01	3 vs. 6	0.02	4 vs. 8	0.05

[a] Abbreviations: Chem., chemical control; Mech., mechanical control; UC, untreated check; RH, rotary hoeing; IR, in-row cultivation.

[b] Bean planting occurred on June 12; rotary hoeing was done on June 26; in-row cultivation was done on July 1 and July 9.

Table 5. The effect of dry bean growth and mechanical control on the cumulative emergence rate, inflection time, cumulative emergence, and maximum emergence rate from fitting the Gompertz function to percent weed seedling emergence in 1996 and 1997.

	K Cumulative emergence rate[a]		Inflection time		Cumulative emergence		Maximum emergence rate	
Treatment[b]	1996	1997	1996	1997	1996	1997	1996	1997
	%/TT		TT		%		%TT	
Crop	0.0118 a	0.0053 a	190.9 a	165.7 a	14.3 a	18.2 a	0.136 a	0.080 a
No Crop	0.0051 b	0.0076 a	350.3 a	147.6 a	11.4 a	16.1 a	0.056 b	0.127 a
UC	0.0066 a	0.0075 a	238.6 a	130.2 b	14.3 ab	14.4 ab	0.086 a	0.111 b
RH	0.0050 a	0.0059 ab	293.2 a	119.1 b	19.7 a	11.5 b	0.105 a	0.071 b
IR	0.0115 a	0.0087 a	389.1 a	116.2 b	13.0 ab	21.2 a	0.135 a	0.167 a
RH + IR	0.0109 a	0.0036 b	161.5 a	261.8 a	4.5 b	19.3 ab	0.058 a	0.067 b

[a] Means in a column with the same letter are not significantly different at the 0.05 probability level using Fisher's Protected LSD.

[b] Abbreviations: UC, untreated check; RH, rotary hoeing; IR, in-row cultivation.

in noncropped plots of the in-row cultivation treatment in 1996 (Figure 1C). Such overestimation occurred between 340 and 630 TT and could be caused by heterogeneous weed emergence, which fluctuated from 11 to 92% within blocks for the cultivation treatment. In contrast, the Gompertz equation estimated seedling emergence in cropped plots when in-row cultivation was used. The effect of the untreated check and rotary hoeing alone and combined with in-row cultivation on weed seedling emergence was described by the Gompertz function (Figures 1A, 1B, and 1D). Initial weed seedling emergence was observed at about 120 TT with 3 to 9% cumulative emergence among treatments.

In 1997, the Gompertz equation described cumulative weed seedling emergence as affected by crop presence and mechanical control in all treatments (Figure 2). Initial weed seedling emergence was first observed at about 80 TT with 6 to 16% cumulative weed seedling emergence among treatments. The close relationship between predicted and dependent observed values in most of the treatments applied in 1997 suggests that Gompertz model could be used to de-

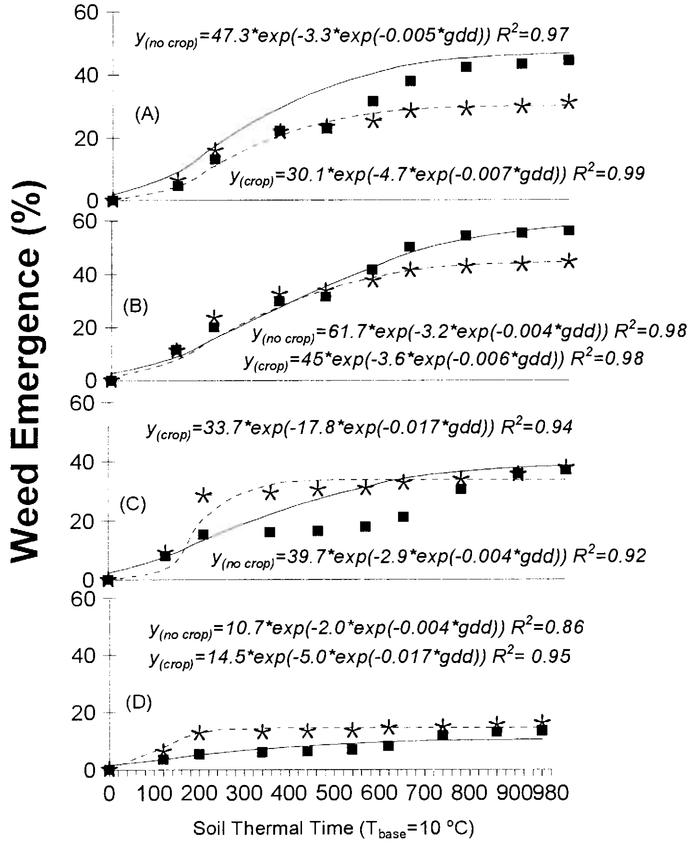

Figure 1. Influence of dry bean (*Phaseolus vulgaris*) and mechanical weed control on cumulative weed seedling emergence in 1996, untreated control (A), rotary hoeing (B), in-row cultivation (C), and rotary hoeing plus in-row cultivation (D). Curves depict estimated values from equations and points are observed values. Dotted line and star symbols represent dry bean presence. Solid line and square symbols are relative to dry bean absence.

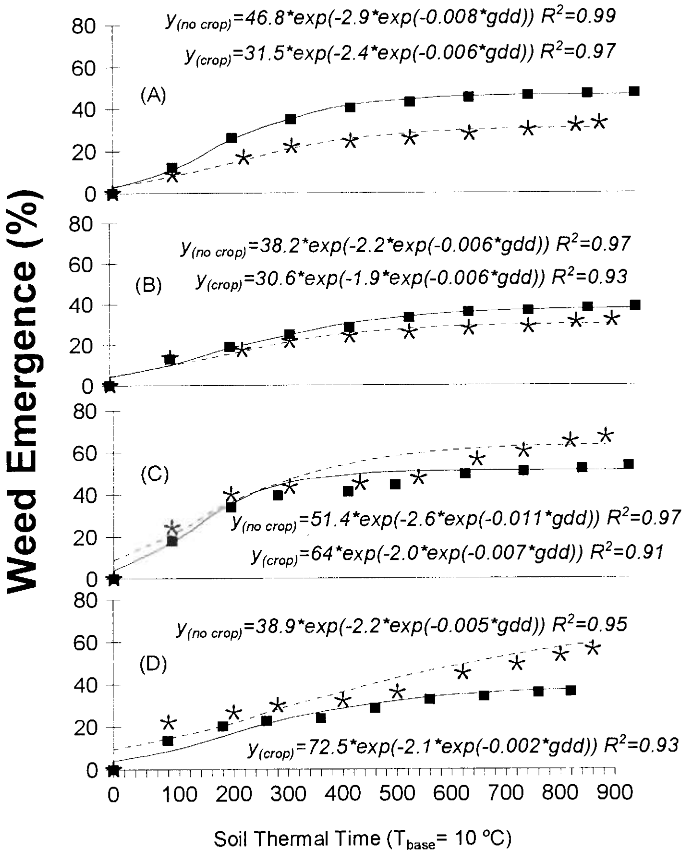

Figure 2. Influence of dry bean (*Phaseolus vulgaris*) and mechanical weed control on cumulative weed seedling emergence in 1997, untreated control (A), rotary hoeing (B), in-row cultivation (C), and rotary hoeing plus in-row cultivation (D). Curves depict estimated values from equations and points are observed values. Dotted line and star symbols represent dry bean presence. Solid line and square symbols are relative to dry bean absence.

Table 6. The effect of no soil disturbance and presence or absence of dry bean (*Phaseolus vulgaris*) on mean soil water in 1996 and 1997 and mean soil temperature in 1997 at Scottsbluff, NE.

	Weeks after crop planting								
Treatment	1	2	3	4	5	6	7	8	9
Soil water (%)									
1996:									
Dry bean presence		5.6 a	2.4 a	5.1 a	6.6 a	7.6 a	8.2 a	4.7 a	8.2 b
Dry bean absence		3.4 a	4.2 a	5.9 a	4.9 a	9.0 a	6.0 a	6.1 a	9.1 a
1997:									
Dry bean presence	12.5 a	9.4 a	17.5 a	12.4 a	13.7 a	14.7 a	20.1 a	15.7 a	19.1 a
Dry bean absence	10.8 a	11.2 a	14.3 a	12.4 a	13.2 a	15.5 a	14.2 a	13.3 a	13.0 a
Soil temperature (C)									
1997:									
Dry bean presence	22.1 a	25.1 a	24.5 a	23.3 a	24.0 a	25.3 a	23.7 a	20.8 b	18.4 b
Dry bean absence	21.6 a	24.5 a	24.9 a	23.3 a	23.6 a	25.9 a	24.1 a	24.0 a	22.0 a

scribe seedling emergence rate and cumulative percent emergence determined under 1997 field conditions.

Overestimation of weed seedling emergence from the Gompertz model in noncropped plots of the in-row cultivation treatment in 1996 was attributed to intermittent weed emergence as stated by Popay and Roberts (1970a). In our study, intermittent weed emergence could be related to the effect of external factors affecting seed germination and weed emergence. For instance, early weed emergence modified by in-row cultivation and then late flushes of weeds induced by environmental factors associated with in-row cultivation. Weed seedling emergence was reduced from 200 to 640 TT in noncropped in-row cultivated plots, but late flushes of annual grasses were measured at 750 and 860 TT. Soil conditions such as an average maximum temperature of 33 C as well as a weekly accumulated rainfall and irrigation of 28 mm recorded at 750 and 860 TT in the experiment could have caused variable annual grass emergence. Benech-Arnold et al. (1990) stated when soil water was not limiting, maximum temperature may release weed seed dormancy, allowing germination to begin. However, germination of each weed species is related to soil temperature thresholds. For instance, Hsu et al. (1985) and Roundy and Biedenbender (1996) pointed out that temperatures from 30 to 35 C were more suitable for warm-season grasses than higher or lower temperatures, which decreased germination rate. This response did not occur in plots with in-row cultivation plus rotary hoeing because the combination of activities resulted in an additive response.

During both years, the lower weed emergence in the untreated check in cropped plots implied that the crop prevented cumulative weed seedling emergence. However, this lower weed emergence was significant only in 1997 (Figures 1 and 2). Differences in soil moisture 2.5 cm deep and soil temperature 8 to 9 wk after planting in plots with presence or absence of dry bean did not explain the differences in weed seedling emergence in 1997 (Table 6). Previous studies have shown that crop canopy reduces the amount and changes the quality of light reaching the soil surface and hence reduces weed seed germination (Knake 1972; Taylorson and Borthwick 1968). Urwin et al. (1996) pointed out that the crop canopy of selected Great Northern dry bean cultivars such as 'Harris' and 'Marquis' enhanced the plant's ability to compete with late-season emerging weeds. In contrast, the presence or absence of corn did not affect the time to reach 25 or 80% cumulative emergence of redroot pigweed seedlings (Oryokot et al. 1997). On the other hand, the presence or absence of soybean did not reduce sicklepod (*Senna obtusifolia* L.) density and biomass (Brecke and Shilling 1996). The cumulative emergence of weed seedlings in cropped and noncropped plots with mechanical treatments was similar in both years (Figures 1B–D and 2B–D).

The Gompertz equations describing weed seedling emergence were different between years because each location had particular features, such as variable weed seed population, viability of the seedbank, and environment (Wilson 1988). Forcella et al. (1997) showed that emergence of summer annual weeds is a changing process from one year or site to the next in response to environment and not a static process. These researchers pointed out that variation in annual weed emergence occurs in response to environmental thresholds that affect secondary dormancy (e.g., induction by soil temperature of 16 C in spring or summer). Schweizer et al. (1998) pointed out that there are few attempts to model the response of weed emergence to tillage because the response depends on species. In this study, hairy nightshade was the predominant species in 1996, whereas in 1997 it was not important. Forcella (1993) stated thermal time was a poor predictor of velvetleaf (*Abutilon theophrasti* Medic.) emergence, but thermal time was a good predictor that described emergence of all weeds in response to the absence or presence of dry bean plants. Although weed seedling emergence occurred throughout the growing season, more weed seedlings emerged in June and early July than in late July and August. Therefore, these data support the importance of cultivating early in the growing season when a majority of the weed seedlings are emerging.

Sources of Materials

[1] Spraying Systems Co. North Avenue at Schmale Road. P.O. Box 7900, Wheaton, IL 60189-7900.

[2] Bezzerides Brothers, Inc. 14142 Ave. 416, Orosi, CA 93647.

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