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Weed Control and Dry Bean (*Phaseolus vulgaris*) Response to In-Row Cultivation, Rotary Hoeing, and Herbicides[1]

MARIO D. AMADOR-RAMIREZ, ROBERT G. WILSON, and ALEX R. MARTIN[2]

Abstract: Field experiments were conducted in 1996 and 1997 to evaluate weed control and dry bean response to mechanical tillage and herbicide treatments. Herbicide treatments were EPTC plus ethalfluralin, dimethenamid, and imazethapyr plus bentazon. Herbicides were applied alone or combined with rotary hoeing and in-row cultivation. Differences in dry bean yields between years were due to differences in weed density. Weed species included redroot pigweed, common lambsquarters, hairy nightshade, wild proso millet, and green foxtail. Weed density in the untreated check plots at the end of the growing season was 35 plants/m² in 1996 and 134 plants/m² in 1997. Dry bean stands were not reduced by rotary hoeing, in-row cultivation, and herbicides in 1996, but in-row cultivation reduced dry bean populations 27% compared to the hand-weeded check in 1997. In-row cultivation and rotary hoeing provided similar weed control in both years. At low weed densities, either mechanical tillage or herbicides alone were effective in suppressing weeds, whereas at higher densities, herbicides combined with mechanical tillage were required for effective control.

Nomenclature: Bentazon; dimethenamid; EPTC; ethalfluralin; imazethapyr; common lambsquarters, *Chenopodium album* L. #[3] CHEAL; dry bean, *Phaseolus vulgaris,* Great Northern 'Beryl'; green foxtail, *Setaria viridis* L. Beauv. # SETVI; hairy nightshade, *Solanum sarrachoides* Sendt. # SOLSA; redroot pigweed, *Amaranthus retroflexus* L. # AMARE; wild proso millet, *Panicum miliaceum* L. # PANMI.

Additional index words: Combinations, herbicides and mechanical tillage, postemergence herbicides, preemergence herbicides, preplant-incorporated herbicides.

Abbreviations: DAP, days after planting; IR, in-row cultivation; POST, postemergence; PRE, preemergence; RH, rotary hoeing.

INTRODUCTION

Weed control in dry bean (*Phaseolus vulgaris*) is required because crop yield reductions of up to 96% can occur if weeds are present throughout the growing season (Solorzano 1983). However, the yield varies depending on weed species, weed density, and time of weed emergence (Blackshaw 1991; Chikoye et al. 1995; Wilson 1993). An appropriate strategy to control weeds in dry bean is to suppress weeds during a critical period of weed interference, which varies from 3 to 5 wk after dry bean planting, depending upon weed species (Blackshaw 1991; Wilson 1993).

Mechanical tillage and herbicides can be used to control weeds in dry bean fields. Mechanical practices such as between-row cultivation usually control weeds located farther away from crop plants; however, weeds nearest the crop plant present the greatest challenge in mechanical weeding. Lovely et al. (1958) showed that rotary hoeing before weed emergence reduced weed infestations by 80% compared to rotary hoeing after weed emergence, which resulted in 40% weed control. However, later research with a powered rotary weeder found that an appropriate time to control weeds with rotary hoeing is the cotyledon to two-leaf growth stage of weeds such as rape (*Brassica campestris* L.) (Pullen and Cowell 1997). Burnside et al. (1998) showed that one rotary hoeing done 1 wk after planting, but before emergence of dry bean plants, reduced weed biomass by 37%, whereas there was no additional benefit to a second rotary hoeing. In a similar study, VanGessel et al. (1995a)

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[2] Former graduate student, University of Nebraska-Lincoln. Current address: INIFAP, Campo Experimental Calera, Apartado Postal #18, Calera V.R., Zac. 98500 Mexico; Professor, University of Nebraska, Panhandle Research and Extension Center, 4502 Avenue I, Scottsbluff, NE 69361-4939; Professor, University of Nebraska-Lincoln, Department of Agronomy, 279 Plant Science Building, Lincoln, NE 68583-0915. Corresponding author's E-mail: amadorrma@latinmail.net.mx.

[3] Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds,* revised 1989. Available only on computer disk from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

reported 50 to 86% weed control when dry bean fields were rotary hoed at the time of crop emergence.

A Bezzerides in-row cultivator that has a pair of spiders, a pair of torsion weeders, and a spinner, has been developed to remove weeds within the crop rows. Schweizer et al. (1992) found that more weeds were removed, crop yields were higher, and gross margin increased when corn (*Zea mays* L.) was cultivated with the Bezzerides in-row cultivator rather than with the standard row crop cultivator. The in-row cultivator was effective in removing weeds 5 cm or less in height. One or two in-row cultivations effectively reduced weed competition to a level at which sorghum [*Sorghum bicolor* (L.) Moench.] yields were not adversely affected (Thomas et al. 1980).

Because the rotary hoe and the in-row cultivator work in the crop row, dry bean plant populations may be reduced, with a possible effect on dry bean seed yield. Crop stand losses due to rotary hoeing and in-row cultivation are inconsistent. Some researchers have estimated crop stand reductions of 9% from rotary hoeing in dry bean (Burnside et al. 1994), of 7 to 14% in soybean (*Glycine max* L.) (Buhler et al. 1992; Buhler and Gunsolus 1996), and of 6 to 32% in corn (Buhler et al. 1995; Mohler et al. 1997; Mulder and Doll 1993), but others have found no reduction (VanGessel et al. 1995a, 1995b).

Standard herbicide treatments for Nebraska dry bean production include products applied preplant incorporated, preemergence (PRE), and postemergence (POST) (University of Nebraska Cooperative Extension 1997). Wilson and Miller (1991) found that EPTC plus ethalfluralin controlled weeds emerging with dry bean and resulted in minimal crop injury compared to imazethapyr. A POST treatment of imazethapyr plus bentazon reduced control of redroot pigweed, giant foxtail (*Setaria faberi* Herrm.), smooth pigweed (*Amaranthus hybridus* L.), and jimsonweed (*Datura stramonium* L.) (Bauer et al. 1995a; Cantwell et al. 1989) compared to imazethapyr applied alone. The reduced weed control can be accounted for by the reduced translocation and absorption of imazethapyr caused by bentazon (Cantwell et al. 1989). Moreover, the POST herbicide combination reduced dry bean injury compared to imazethapyr applied alone (Bauer et al. 1995b). Bauer et al. (1995a) found that the inhibition of production and translocation of photoassimilates by bentazon reduce phloem transport of imazethapyr.

The effectiveness of in-row weed control can be increased by combining rotary hoeing and in-row cultivation with herbicides. The need to combine mechanical and chemical weed control practices is dictated by weed density. At high weed densities, mechanical management systems should be combined with herbicides; however, mechanical weed control methods provided sufficient weed control at low weed densities (Buhler et al. 1992; Hooker et al. 1997). The effectiveness of mechanical weeding was improved with herbicides because preemergence herbicide treatment reduced weed density and size prior to rotary hoeing and in-row cultivation in soybean (Hooker et al. 1997).

Standard cultivation is often used to control weeds emerging between rows, but often weeds growing in the crop row are missed. Crop yield losses due to weeds remaining in the field have been estimated to be 14% for dry bean in the mountain States of the United States (Chandler et al. 1984). In-row cultivators would contribute to weed management programs by removing weeds located in the crop row. Therefore, the objective of this study was to evaluate weed control and dry bean yield response to rotary hoeing, in-row cultivation, or herbicides.

MATERIALS AND METHODS

Field experiments were conducted in 1996 and 1997 at different sites near the University of Nebraska Panhandle Research and Extension Center at Scottsbluff, NE (41°56′N, 103°41′W, 1,220 m above sea level). The plots were established on a Tripp sandy loam soil (course-silty, mixed mesic Typic Haplustoll) with pH 7.6 and 1.0% organic matter. Beryl Great Northern dry edible beans were planted on June 8, 1996, and June 12, 1997, in rows spaced 76 cm apart at a rate of 67 kg/ha. Bean population was approximately 210,000 plants/ha. Sprinkler irrigation was applied in addition to rainfall. The first irrigation was 10 d after planting (DAP) in 1996 and 17 DAP in 1997, and subsequent irrigation was applied weekly. Unfortunately, the amount of supplemental water applied by irrigation was not measured; however, supplemental irrigation is a common practice in this area.

The experimental design was a randomized complete block with four replicates. Plot size was four rows wide by 12 m long. A 10-m alleyway between replicate blocks was established to obtain the desired tractor speed before entering the plots with the cultivation equipment. To evaluate the effectiveness of rotary hoeing and in-row cultivation alone or combined with herbicides, 16 treatments, including an untreated check, were established. Weed control treatments were (1) rotary hoeing (RH), (2) in-row cultivation (IR), (3) RH plus IR, (4) EPTC

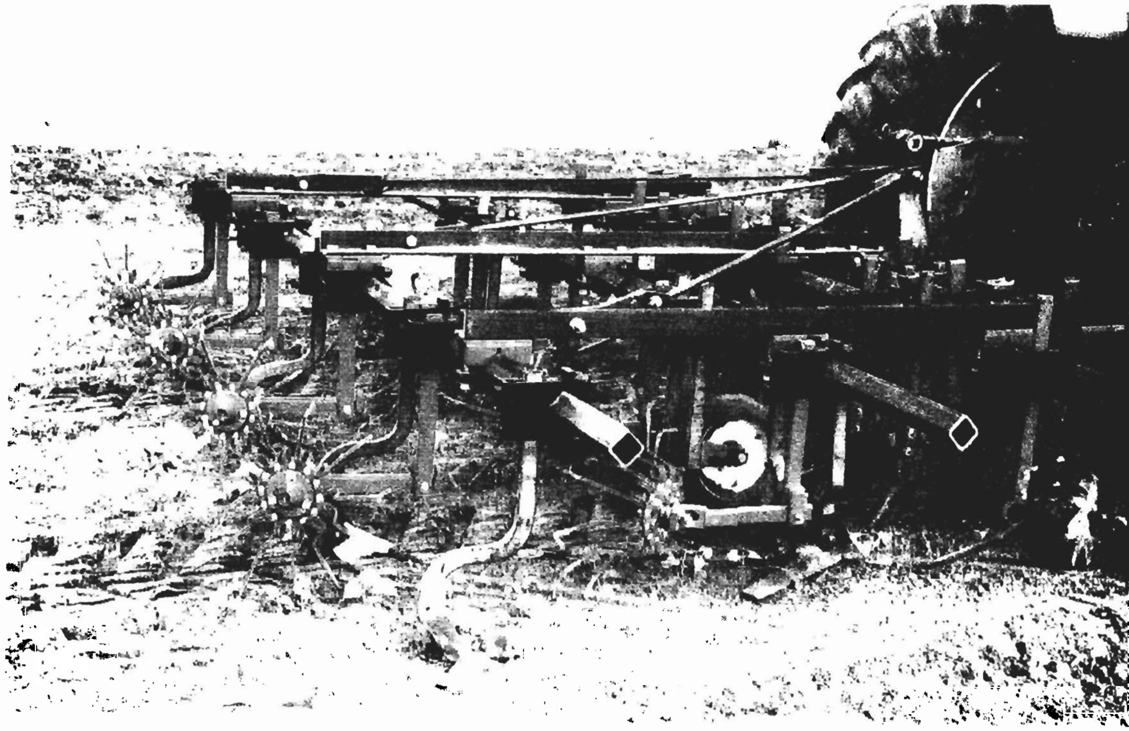

Figure 1. In-row cultivator used in the experiment with spiders in the front, torsion bar weeders in the middle, and spinners in the rear.

plus ethalfluralin, (5) EPTC plus ethalfluralin plus RH, (6) EPTC plus ethalfluralin plus IR, (7) EPTC plus ethalfluralin plus RH plus IR, (8) dimethenamid, (9) dimethenamid plus RH, (10) dimethenamid plus IR, (11) dimethenamid plus RH plus IR, (12) imazethapyr plus bentazon, (13) imazethapyr plus bentazon plus RH, (14) imazethapyr plus bentazon plus IR, and (15) imazethapyr plus bentazon plus RH plus IR. A hand-weeded check was included in 1997.

EPTC plus ethalfluralin was applied at 2.4 plus 0.83 kg ai/ha, dimethenamid at 1.1 kg ai/ha, and imazethapyr plus bentazon at 0.070 plus 0.56 kg ai/ha. Herbicides were applied with a tractor-mounted sprayer equipped with six flat-fan nozzles.[4] EPTC plus ethalfluralin was applied PPI and incorporated with a power-driven rotary tiller to a depth of 5 to 8 cm, dimethenamid was applied PRE, and imazethapyr plus bentazon was applied POST when the crop was in the second trifoliate leaf stage (20 DAP) and weeds were ≤ 3.0 cm tall. Postemergence herbicides were combined with surfactant[5] at 500 ml/ha. A John Deere rotary hoe[6] was used to 1.5 cm deep at the cotyledonary stage of crop growth, whereas in-row cultivation was done at the unifoliate and fourth trifoliate leaf stages of crop growth. In-row cultivation was done with a Bezzerides[7] in-row cultivator (Figure 1). The front spiders of the in-row cultivator were adjusted to move soil away from the crop row. Torsion bar weeders were 15 to 18 cm apart at the narrowest point and were adjusted to 2.5 cm below the soil surface. Spinners were adjusted so that they moved on the soil through the crop row. Rotary hoeing was performed at a speed of 5 mph and in-row cultivation at 4 mph.

Four permanent quadrats 18 cm wide by 1.5 m long were established in the two center crop rows of each plot. Each row contained two quadrats approximately 2.0 m apart. Weed populations in each quadrat were identified by species and counted (plants/m^2) weekly throughout the growing season. The species included redroot pigweed (*Amaranthus retroflexus*), common lambsquarters (*Chenopodium album*), hairy nightshade (*Solanum sarrachoides*), wild proso millet (*Panicum miliaceum*), and green foxtail (*Setaria viridis*). For ease of counting and data handling, annual grasses were not counted by species. Crop plants were counted (plants/m^2) in 7.6 m of the two center rows at 39 DAP in 1996 and at 13 and 41 DAP in 1997. When 80% of the plant leaves were yellow (senesced), beans were harvested by hand-pulling

[4] Teejet XR 11002, Spraying Systems Co., North Avenue at Schmale Road, P. O. Box 7900, Wheaton, IL 60189.

[5] X-77, a mixture of alkyaryl-polyoxyethylene glycols, free fatty acids, and isopropanol. Chevron Chemicals Co., 575 Market Street, San Francisco, CA 94105.

[6] Deere and Company, One John Deere Place, Moline, IL 61265.

[7] Bezzerides Brothers, Inc., 14142 Avenue 416, Orosi, CA 93647

Table 1. Air temperature and precipitation received during the growing season at Scottsbluff, NE.

Weeks after planting	Mean temperature		Precipitation[a]	
	1996	1997	1996	1997
	C		mm	
1	19.6	18.7	10	5
2	20.9	20.2	2	14
3	22.2	22.5	6	1
4	24.3	20.9	3	2
5	22.6	23.0	0	1
6	21.6	24.3	38	4
7	23.3	23.2	0	46
8	21.4	22.3	3	15
9	21.1	18.5	20	26
Total	—	—	82	114
Average	21.9	21.5		

[a] Precipitation amounts do not include irrigation.

plants from a 4.65-m^2 area in the two center rows of each plot. Plants were air dried in the field for approximately 5 d and threshed and seed weights were recorded.

ANOVA was performed using the General Linear Model procedure of SAS (1996) on weed densities and dry bean stand and seed yield. Year by treatment interaction for dry bean yield data was significant; therefore, data for each year were subjected to separate ANOVA. Treatment means were separated using the LSD test at the 5% level of significance.

RESULTS AND DISCUSSION

Climate Conditions. Mean air temperatures averaged over the growing season in both years were similar; however, averaged over a week, a 3.2 or a 2.7 C difference between years in week 4 or week 6, respectively, could affect weed growth (Table 1). Although the amount of water applied by supplemental irrigation was not measured, sites were adequately irrigated to compensate for the low precipitation that occurred in both years. Precipitation during the first 4 wk after planting was 21 mm in 1996 and 22 mm in 1997. The total precipitation during the growing season was 32 mm higher in 1997 than in 1996.

Weed Control. Higher weed pressure was present in 1997 than in 1996 (Table 2). Factors such as location of the plots, crop rotation history, and weed seedbank could have contributed to these differences. High weed density in 1997 could be explained by the establishment of an experiment with redroot pigweed in 1996 at this site. Redroot pigweed was the predominant weed in the untreated check in 1997. In 1996, in-row cultivation alone or combined with rotary hoeing reduced weed density 66 and 57%, respectively, compared to the untreated check at 53 DAP (Table 2). In 1997, weed densities counted 13 DAP in plots with mechanical weeding were similar to the untreated check. However, rotary hoeing, in-row cultivation, and the combination of both methods reduced the stand of weeds 61, 33, and 77% respectively, compared to the untreated check at 34 DAP (Table 2). There was no benefit in weed control by combining mechanical weeding and herbicides compared to herbicides alone, although the use of any weed control combination treatment reduced the weed density more than that in the untreated check in both years. Plots with rotary hoeing or in-row cultivation showed late weed flushes at 53 DAP in 1996, which could interfere with dry bean harvest. Rotary hoeing and in-row cultivation treatments decreased weed density from 13 to 55 DAP in 1997 (Table 2), although at the end of the season, weed densities in plots that were rotary hoed or cultivation in-row were 38 and 87 plants/m^2, respectively, which was higher than in 1996, implying possible weed interference. VanGessel et al. (1998) found that weeds at the end of the growing season may cause dry bean yield loss by interfering with harvest and prolong the drying time of windrowed plants.

In 1997, the individual application of EPTC plus ethalfluralin reduced weed density 90 and 91% more than from dimethenamid or imazethapyr plus bentazon, respectively (Table 2). EPTC plus ethalfluralin controlled more weeds than mechanical weeding throughout the growing season in 1997, supporting previous findings from VanGessel et al. (1998), who found that EPTC and ethalfluralin provided effective control of layby weed populations in dry bean fields. In 1997, weed density in plots treated with dimethenamid plus rotary hoeing and in-row cultivation was similar to that in plots treated with imazethapyr plus bentazon plus rotary hoeing and in-row cultivation at 34 DAP (Table 2). Treatments containing imazethapyr plus bentazon reduced weed density more than the untreated check at 34 and 55 DAP in both years. Hart et al. (1997) reported weed reduction up to 88% with imazethapyr applied POST to soybean, whereas in our study, imazethapyr plus bentazon without mechanical weeding, averaged over years and over 53 and 55 DAP, resulted in 62% weed reduction. The reduction in weed control can be attributed to the antagonistic role of bentazon on translocation and absorption of imazethapyr (Cantwell et al. 1989), in addition to differences in weed species and herbicide application timing between both studies.

In 1996, treatments containing EPTC plus ethalflur-

Table 2. Total weed density during the 1996 and 1997 growing seasons.[a]

Treatment[b]	Weed density[c] 1996 8 DAP	1996 29 DAP	1996 53 DAP	1997 13 DAP	1997 34 DAP	1997 55 DAP
	Plants/m²					
Untreated check	7	17	35	269	208	134
RH	5	5	24	156	81	62
IR	4	2	12	279	140	99
RH + IR	5	4	15	217	48	44
EPTC + ethalfluralin	0	0	1	0	0	5
RH + EPTC + ethalfluralin	0	0	0	0	0	9
IR + EPTC + ethalfluralin	0	0	0	1	1	11
RH + IR + EPTC + ethalfluralin	0	0	0	0	0	15
Dimethenamid	1	5	6	77	52	48
RH + dimethenamid	2	3	3	22	8	14
IR + dimethenamid	5	5	6	64	28	54
RH + IR + dimethenamid	3	1	1	76	20	23
Imazethapyr + bentazon	—	2	6	—	73	58
RH + imazethapyr + bentazon	—	7	10	—	27	25
IR + imazethapyr + bentazon	—	0	0	—	41	35
RH + IR + imazethapyr + bentazon	—	0	2	—	27	34
LSD (0.05)	4	6	14	145	67	38

[a] Abbreviations: RH, rotary hoe; IR, in-row cultivation; DAP, days after planting.

[b] Rotary hoeing was done 8 and 14 DAP in 1996 and 1997, respectively; in-row cultivation was done 18 and 32 DAP in 1996 and 19 and 27 DAP in 1997.

[c] Dashes indicate data are not available for comparisons because herbicides were applied at 20 DAP.

alin reduced weed densities of redroot pigweed, wild proso millet, hairy nightshade, and common lambsquarters 53 DAP compared with the untreated check (Table 3). In-row cultivation reduced redroot pigweed density by 62% and wild proso millet by 92% when plots were evaluated 53 DAP and compared with the untreated control. Rotary hoeing, which was applied early in the growing season, failed to reduce the density of late-emerging redroot pigweed and wild proso millet.

In 1997, hairy nightshade density declined 100% in

Table 3. Weed densities during the growing season in 1996.[a]

Treatment[b]	Weed density[c] AMARE 8 DAP	AMARE 53 DAP	PANMI 8 DAP	PANMI 53 DAP	SOLSA 8 DAP	SOLSA 53 DAP	CHEAL 8 DAP	CHEAL 53 DAP
	Plants/m²							
Untreated check	1	13	4	13	2	4	0	5
RH	1	8	1	7	3	3	0	6
IR	0	5	2	1	2	2	1	2
RH + IR	0	5	3	8	2	1	0	1
EPTC + ethalfluralin	0	0	0	0	0	1	0	0
RH + EPTC + ethalfluralin	0	0	0	0	0	0	0	0
IR + EPTC + ethalfluralin	0	0	0	0	0	0	0	0
RH + IR + EPTC + ethalfluralin	0	0	0	0	0	0	0	0
Dimethenamid	0	1	1	2	1	2	0	1
RH + dimethenamid	0	0	0	0	2	1	0	1
IR + dimethenamid	1	1	1	1	4	2	0	2
RH + IR + dimethenamid	0	0	1	1	—	1	—	0
Imazethapyr + bentazon	—	2	—	3	—	0	—	0
RH + imazethapyr + bentazon	—	3	—	5	—	1	—	1
IR + imazethapyr + bentazon	—	0	—	0	—	0	—	0
RH + IR + imazethapyr + bentazon	—	0	—	2	—	0	—	0
LSD (0.05)	1	6	2	6	3	2	1	4

[a] Abbreviations: RH, rotary hoe; IR, in-row cultivation; DAP, days after planting; AMARE, redroot pigweed (*Amaranthus retroflexus*); PANMI, wild proso millet (*Panicum miliaceaum*); SOLSA, hairy nightshade (*Solanum sarrachoides*) CHEAL, common lambsquarters (*Chenopodium album*).

[b] Rotary hoeing was done 8 DAP; in-row cultivation was done 18 and 32 DAP.

[c] Dashes indicate data are not available for comparisons because herbicides were applied at 20 DAP.

Table 4. Weed densities during the growing season in 1997.[a]

Treatment[b]	Weed density[c] AMARE 13 DAP	AMARE 55 DAP	CHEAL 13 DAP	CHEAL 55 DAP	SOLSA 13 DAP	SOLSA 55 DAP	Annual gasses[d] 13 DAP	Annual gasses[d] 55 DAP
	Plants/m^2							
Untreated check	171	81	78	46	3	0	17	7
RH	88	43	50	17	0	0	18	3
IR	180	66	55	22	1	0	44	11
RH + IR	22	11	174	29	2	0	19	4
EPTC + ethalfluralin	0	5	0	1	0	0	0	0
RH + EPTC + ethalfluralin	0	6	0	3	0	0	0	1
IR + EPTC + ethalfluralin	0	6	1	3	0	0	0	2
RH + IR + EPTC + ethalfluralin	0	8	0	5	0	0	0	2
Dimethenamid	2	13	73	34	0	0	3	1
RH + dimethenamid	2	6	19	8	1	0	1	1
IR + dimethenamid	7	31	51	21	1	0	5	2
RH + IR + dimethenamid	0	5	73	18	2	0	2	0
Imazethapyr + bentazon	—	17	—	39	—	0	—	3
RH + imazethapyr + bentazon	—	3	—	20	—	0	—	2
IR + imazethapyr + bentazon	—	4	—	29	—	0	—	2
RH + IR + imazethapyr + bentazon	—	21	—	12	—	0	—	2
LSD (0.05)	125	42	141	42	2	0	22	5

[a] Abbreviations: RH, rotary hoe; IR, in-row cultivation; DAP, days after planting; AMARE, redroot pigweed (*Amaranthus retroflexus*); CHEAL, common lambsquarters (*Chenopodium album*); SOLSA, hairy nightshade (*Solanum sarrachoides*).

[b] Rotary hoeing was done 14 DAP; in-row cultivation was done 19 and 27 DAP.

[c] Dashes indicate data are not available for comparisons because herbicides were applied at 20 DAP.

[d] Includes green foxtail (*Setaria viridis*), yellow foxtail (*Setaria lutescence*), and wild proso millet (*Solanum sarrachoides*).

the untreated check, and densities of redroot pigweed, common lambsquarters, and annual grasses declined 53, 41, and 59%, respectively, from 13 to 55 DAP (Table 4). The decline in weed populations was probably due to plant competition among the weeds. Again, treatments containing EPTC plus ethalfluralin effectively controlled redroot pigweed, common lambsquarters, and annual grasses at 13 and 55 DAP. In-row cultivation plus rotary hoeing controlled redroot pigweed 87% compared with the untreated check at both sampling dates. Treatments containing dimethenamid reduced weed densities of redroot pigweed at 13 and 55 DAP and annual grasses at 55 DAP compared with the untreated check. Similar results were reported by Van Wychen et al. (1996), who observed 92% redroot pigweed control from dimethenamid. Imazethapyr plus bentazon without mechanical weeding reduced redroot pigweed density by 79% at 55 DAP, but combinations of rotary hoeing or in-row cultivation with imazethapyr plus bentazon suppressed 96 and 95% of redroot pigweed compared with the untreated control, respectively. At 13 DAP, none of the treatments were different from the untreated check, whereas at 55 DAP, EPTC combined with rotary hoeing or in-row cultivation were the only treatments that had less common lambsquarters than the untreated check. Imazethapyr plus bentazon did not control common lambsquarters compared with the untreated check, supporting the finding of Bauer et al. (1995a). Combining rotary hoeing and in-row cultivation with imazethapyr plus bentazon did not increase redroot pigweed and grass control compared to imazethapyr plus bentazon without cultivation.

Dry Bean Population and Yield. Except for imazethapyr plus bentazon combined with rotary hoeing and in-row cultivation, dry bean plant populations were not reduced by rotary hoeing, in-row cultivation, or herbicides in 1996 (Table 5). In 1997, the plant population of dry bean counted 13 DAP did not differ among treatments but differed at 41 DAP. Although in our study in-row cultivation did not reduce dry bean population compared to rotary hoeing, VanGessel et al. (1998) estimated reductions of bean plant populations of 13% by rotary hoeing compared to in-row cultivation. A different response between years of the effect of the in-row cultivator on dry bean stands could be attributed to poor weed control rather than to mechanical adjustment problems. These results are supported by the finding of Schweizer et al. (1992), who also found a different response between years in corn with the use of the in-row cultivator but could not explain the difference.

Dry bean yield in 1996 ranged from 1,029 to 1,704 kg/ha and did not appear to be related to treatment effects (Table 5). The untreated check yielded higher than

Table 5. Yield and plant population of dry bean (*Phaseolus vulgaris*) as a function of rotary hoeing, in-row cultivation, and herbicides in 1996 and 1997.[a]

Treatment[b]	Bean population[c] 1996 39 DAP	Bean population[c] 1997 13 DAP	Bean population[c] 1997 41 DAP	Yield 1996	Yield 1997
	Plants/m²			kg/ha	
Untreated check	15	12	13	1,582	4
Hand-weeded check	—	12	15	—	2,832
RH	13	11	14	1,145	161
IR	14	11	11	1,390	127
RH + IR	14	12	11	1,259	505
EPTC + ethalfluralin	14	13	15	1,520	1,842
RH + EPTC + ethalfluralin	13	13	13	1,584	2,263
IR + EPTC + ethalfluralin	13	12	12	1,337	2,453
RH + IR + EPTC + ethalfluralin	13	12	14	1,704	2,592
Dimethenamid	14	11	15	1,029	790
RH + dimethenamid	15	13	15	1,258	1,303
IR + dimethenamid	14	12	13	1,180	1,335
RH + IR + dimethenamid	13	13	14	1,278	894
Imazethapyr + bentazon	14	13	14	1,668	1,507
RH + imazethapyr + bentazon	13	13	13	1,166	1,376
IR + imazethapyr + bentazon	14	14	14	1,359	1,749
RH + IR + imazethapyr + bentazon	12	12	13	1,353	1,921
LSD (0.05)	2	3	3	467	820

[a] Abbreviations: RH, rotary hoe; IR, in-row cultivation; DAP, days after planting.
[b] Rotary hoeing was done 8 and 14 DAP in 1996 and 1997, respectively; in-row cultivation was done 18 and 32 DAP in 1996 and 19 and 27 DAP in 1997.
[c] Dashes mean treatment not present in 1996.

average, probably because of the low weed population present at this site. The reason for the low yield from dimethenamid is not apparent because bean stand and weed control were similar to other treatments. Also, yields in the dimethenamid plus rotary hoeing and/or in-row cultivation plots were not significantly less than in the untreated check. With greater weed densities in 1997, weed control treatments provided different degrees of control, and crop yields responded to weed control. Dry bean seed yields were similar for rotary hoeing, in-row cultivation, and the combination of both methods, and they were 94, 96, and 82% lower than the handweeded check (Table 5). Although the benefit of combining mechanical in-row weed control and chemical weed control techniques has been described by several authors (Buhler et al. 1992; Burnside et al. 1994; Lovely et al. 1958; VanGessel et al. 1998), no benefit was observed in our study. Weeds in the untreated check treatment reduced dry bean seed yield over 99% compared with the hand-weeded check.

The use of rotary hoeing in crops such as corn, soybean, and dry bean has been widely studied, but the use of in-row cultivation in dry bean is recent. Our results suggest that the effectiveness of in-row weed control techniques is closely related to weed pressure. At reduced weed densities, the use of rotary hoeing, in-row cultivation, or herbicides alone was effective in suppressing weeds. Under high weed densities, mechanical in-row control did not reduce weed density enough to prevent crop yield loss. The advantage of using rotary hoeing and in-row cultivation is in the control of early-emerging weeds. EPTC plus ethalfluralin applied before planting and then incorporated provided better weed control throughout the growing season than dimethenamid applied PRE or imazethapyr plus bentazon applied POST. Benefits from combining EPTC plus ethalfluralin and rotary hoeing or in-row cultivation were not observed because of the effectiveness of these herbicides. Dimethenamid and imazethapyr plus bentazon were not as effective as EPTC plus ethalfluralin in suppressing weeds and may benefit from being combined with rotary hoeing and in-row cultivations.

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