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Integrating Irrigation, Tillage, and Herbicides for Weed Control in Dry Bean

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Field trials were conducted from 2010 through 2012 to evaluate the integration of three factors: overhead irrigation after planting great northern dry bean; three methods of seedbed preparation: no-tillage, one or two diskings; and eight weed control treatments on dry bean development and weed control. The previous crop each year was corn. Overhead irrigation with 13 mm of water immediately after herbicide application and planting in early June did not improve or reduce herbicide efficacy but where herbicides were not utilized, irrigation increased weed emergence. Soil crusting increased in 2 of 3 yr when soil was disked at a 20-cm depth before planting. Crop injury from herbicides applied PRE increased when soil crusting occurred. No tillage before planting reduced crop injury from herbicides in 2010 and 2011 and weed density in 2012. Dry bean injury was minimal from herbicides applied PRE except for flumioxazin, which reduced crop density in 2011 and 2012. Imazamox plus bentazon applied POST caused early-season dry bean injury in 2 of 3 yr and resulted in a reduction in crop seed yield compared to dimethenamid-P or halosulfuron applied PRE. As producers move away from intensive tillage before planting to reduced tillage or no-tillage production systems, the results of this experiment show that dimethenamid-P, halosulfuron, pendimethalin, and *S*-metolachlor can be utilized PRE to provide acceptable weed control and crop selectivity. Although flumioxazin applied PRE reduced plant density, Great Northern dry bean yields were not affected by the loss of plant stand.

Nomenclature: Bentazon; dimethenamid-P; flumioxazin; glyphosate; halosulfuron; imazamox; *S*-metolachlor; dry bean, *Phaseolus vulgaris* L.; 'Orion' and 'GN3138′.
Key words: Disking, dry edible bean, no-tillage, soil crusting.

Se realizaron estudios de campo desde 2010 hasta 2012 para evaluar la integración de tres factores: riego por aspersión después de la siembra de frijol común Great Northern; tres métodos de preparación de la cama de siembra: labranza cero, una, o dos pases de disco; y ocho tratamientos de control de malezas, sobre el desarrollo del frijol y el control de malezas. En cada año, el cultivo previo fue maíz. El riego por aspersión con 13 mm de agua, inmediatamente después de la aplicación de herbicidas y la siembra al inicio de Junio, no mejoró ni redujo la eficacia de los herbicidas, pero donde no se utilizó herbicidas, el riego aumentó la emergencia de malezas. La formación de costras (compactación) en la superficie del suelo aumentó en 2 de 3 años cuando el suelo fue arado con discos a 20 cm de profundidad antes de la siembra. El daño del cultivo producido por herbicidas aplicados PRE aumentó cuando ocurrió la formación de costra en la superficie del suelo. La labranza cero antes de la siembra redujo el daño del cultivo producto de los herbicidas en 2010 y 2011 y también la densidad de malezas en 2012. El daño al frijol fue mínimo con herbicidas aplicados PRE excepto con flumioxazin, que redujo la densidad del cultivo en 2011 y 2012. Imazamox más bentazon aplicados POST causaron daño al frijol temprano en la temporada en 2 de 3 años, lo que resultó en una reducción en el rendimiento de semilla del cultivo al compararse con dimethenamid-P o halosulfuron aplicados PRE. Con el cambio, por parte de los productores de labranza intensiva hacia labranza reducida o cero, los resultados de este experimento muestran que dimethenamid-P, halosulfuron, pendimethalin, y *S*-metolachlor pueden ser utilizados PRE para brindar un control de malezas aceptable y selectividad en el cultivo. Aunque flumioxazin aplicado PRE redujo la densidad de plantas, los rendimientos del frijol Great Northern no fueron afectados por la pérdida de plantas establecidas.

Dry bean is important to the economy of the High Plains of the United States. In 2010, the states of Colorado, Nebraska, and Wyoming produced 17% of the U.S. dry bean production with 15% of the planted hectares (USDA 2013). Average yields were as follows: Colorado, 2,130 kg ha^{-1}; Nebraska, 2,309 kg ha^{-1}; and Wyoming, 2,444 kg ha^{-1} compared to U.S. production of 1,935 kg ha^{-1}. The area produces 88% of the great northern, 29% of the light red kidney, and 25% of the pinto production in the United States. Because of the arid climate most dry bean is grown with

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supplemental irrigation. Weed species that have caused production problems in the crop are redroot pigweed (*Amaranthus retroflexus* L.), common lambsquarters (*Chenopodium album* L.), hairy nightshade (*Solanum sarrachoides* Sendt.), and kochia (*Kochia scoparia* L.) (Wilson et al. 1980).

Growers traditionally have prepared a seedbed by moldboard plowing, roller harrowing, applying herbicide application, and incorporation of herbicide with a second roller harrowing (Schwartz et al. 2004). Because of high expense related to fuel cost and erosion concerns associated with intensive preplant tillage, producers are switching to reduced tillage or no-tillage practices and utilizing herbicides applied after planting with no mechanical incorporation (Schwartz et al. 2004). Herbicides applied PRE after planting rely on rainfall or irrigation to move the herbicide off the crop residue and into the soil, where herbicides are then activated by increasing soil moisture (Stickler et al. 1969). For example, Holmes and Sprague (2013) reported that the degree of common lambsquarters control in dry bean from halosulfuron or halosulfuron plus *S*-metolachlor PRE was highly dependent on precipitation, where the lack of rainfall after dry bean planting resulted in poor incorporation of PRE herbicide and consequently poor common lambsquarters control. In addition, the amount of crop residue remaining after tillage can reduce the bioactivity of PRE herbicides by preventing them from reaching the soil surface (Buhler 1992). For instance, the interception of chloroacetamide herbicides by increasing amounts of crop residues have been shown to reduce weed control (Banks and Robinson 1986).

Recent trends in dry bean weed management have shown increased use of imazethapyr, imazamox, and fomesafen applied POST (Wilson and Miller 1991; Wilson 2005). Imazamox plus bentazon POST provided equal or greater common lambsquarters control than halosulfuron plus *S*-metolachlor PRE (Holmes and Sprague 2013). Bentazon plus imazamox POST provided more consistent hairy nightshade control than either bentazon or imazamox alone (Blackshaw et al. 2000). The challenge of using herbicides for weed control in dry bean is that crop safety can vary greatly between market classes. For instance, Soltani et al. (2005) reported that flumioxazin injury was affected by time of application, rate of application, and type of dry bean. Crop injury that ranged from no effect to significant yield reduction was reported with POST application of imazamox, cloransulam-methyl, and halosulfuron-methyl tank-mixed with bentazon for several bean market classes (Sikkema et al. 2004; Soltani et al. 2006, 2012).

Little research has been reported on the influence of overhead sprinkler irrigation in combination with no-tillage or reduced-tillage planting practices on herbicide efficacy and great northern dry bean injury. Therefore the objective of this research was to evaluate the integration of three factors: overhead irrigation after planting, seedbed preparation, and herbicides on weed control and crop injury.

Materials and Methods

Field trials were conducted in 2010, 2011, and 2012 at the University of Nebraska Panhandle Research and Extension Center near Scottsbluff, NE. Plots were located in different fields each year on a Tripp sandy clay loam (Typic Haplustoll) with pH 7.9 to 8.0 and 1.0 to 1.1% organic matter. The crop prior to these studies was corn. Consequently, preparation consisted of shredding corn stalks in early May followed by glyphosate at 0.84 kg ha^{-1} in late May (Table 1).

The experiment was a three-factorial split-split plot set in a randomized complete block design. The two main plots were not irrigated or irrigated by an overhead sprinkler with 13 mm of water after planting. There were three subplots that consisted of different methods of seedbed preparation: no tillage, or one or two diskings. Corn residue was estimated before dry bean planting by using the photo comparison method (Shelton and Jasa 1995). The percentage of soil surface covered with corn residue after seed bed preparation was approximately 90% for no tillage, 50% for single disking, and 25% for double disking. Sub-subplots were herbicide treatments: five herbicides applied after planting PRE, two herbicide treatments applied POST when dry bean reached the first trifoliate growth stage, and nontreated (Table 2). Each treatment was replicated four times and plot width was 3.4 m, with six rows spaced 56 cm apart and

Table 1. Field operations, planting, herbicide application, data collection, and harvest dates.

Field operation	2010	2011	2012
Shredding corn stalks	May 5	May 6	May 4
Glyphosate application	May 19	May 24	May 23
Disking	June 1	June 2	June 4
Planting	June 9	June 5	June 11
Dry bean variety: great northern	'Orion'	'Orion'	'GN3138'
PRE herbicide application	June 11	June 6	June 11
Postplanting irrigation date	None	June 8	June 11
Postplanting irrigation amount	None	13 mm	13 mm
First postplanting rainfall date	June 11	June 9	June 15
Postplanting rainfall, first 7 d	55 mm	18 mm	3 mm
Postplanting rainfall, 8 to 14 d	8 mm	42 mm	6 mm
POST herbicide application	July 2	June 27	June 29
Dry bean injury rating	July 16	July 12	July 6
Dry bean density	July 6	July 7	July 6
Weed density	July 23	July 18	July 16
Dry bean yield	September 23	September 6	September 20

plot length of 6.7 m. Herbicides were applied using a tractor-mounted compressed air sprayer calibrated to deliver 197 L ha^{-1} through 11002 VS spray nozzles (Tee Jet, Spraying Systems Co., Wheaton, IL).

Table 2. Weed control treatments and herbicide rates utilized in from 2010 through 2012.

Weed control treatment	Rate	Timing
	ai ha^{-1}	
Dimethenamid-P[a]	0.73 kg	PRE
Flumioxazin	35 g	PRE
Halosulfuron	35 g	PRE
Halosulfuron + bentazon + NIS[b]	35 g + 0.21 kg + 0.25% v/v	POST
Imazamox + bentazon + NIS	35 g + 0.56 kg + 0.25 % v/v	POST
Pendimethalin	1.06 kg	PRE
S-metolachlor	1.06 kg	PRE
Nontreated	—	—

[a] Dimethenamid-P (Outlook®, BASF Corporation, Research Triangle Park, NC, http://agproducts.basf.us/); flumioxazin (Valor®, Valent U.S.A. Corporation, Walnut Creek, CA, http://www.valent.com/agriculture); halosulfuron (Permit®, Gowan Company, Yuma, AZ, http://www.gowanco.com); imazamox (Raptor®, BASF Corporation, Research Triangle Park, NC, http://agproducts.basf.us); bentazon (Basagran®, BASF Corporation, Research Triangle Park, NC, http://agproducts.basf.us); pendimethalin (Prowl H_2O®, BASF Corporation, Research Triangle Park, NC, http://agproducts.basf.us); *S*-metolachlor (Dual II Magnum®, Syngenta Corporation, Wilmington, DE, http://www.syngenta-us.com); nonionic surfactant (X77®, Loveland Products, Loveland, CO, http://www.lovelandproducts.com).

[b] Abbreviation: NIS, nonionic surfactant

The dry bean variety planted in 2010 and 2011 was 'Orion' and in 2012 'Taurus/GN3138'. These two great northern varieties have an upright medium profile and are closely related in that they have one parent in common with each other (Kelley Bean Co., Scottsbluff, NE). The target plant population was 210,000 plants ha^{-1} and dry bean seed was sown at a 5-cm depth in early June using a Monosem planter equipped with Yetter trashmaster/residue managers (Monosem Incorporated, Edwardsville, KS; Yetter Manufacturing Co., Colchester, IL) (Table 1). Following the initial irrigation treatment all plots were irrigated as needed throughout the season.

Crop injury was evaluated visually approximately 2 wk following POST herbicide treatment on a scale of 0 to 100%, with 0% indicating no injury and 100% indicating that all plants were dead (Table 1). Dry bean and weed density were measured by counting plants in an 8-m^{-2} area in the center of each plot in early July. Dry bean seed yield was determined by hand-pulling plants within a 3.4-m^{-2} area. Dry bean plants were air-dried in the field for 7 d before seeds were threshed and weighed.

Data were subjected to ANOVA using PROC MIXED in SAS 9.2 (SAS Institute Inc., Cary, NC). Treatment means were compared using Fisher's protected LSD at the $\alpha < 0.05$ level of significance. Data were combined over years if there was not a significant year by seedbed preparation method or weed control treatment interaction.

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Table 3. Dry bean injury, density, seed yield, and weed density near Scottsbluff, NE, over the period from 2010 through 2012.[a]

Factor	2010	2011	2012
Dry bean density			
(1,000 plants ha^{-1})	66 c	164 b	204 a
Dry bean seed yield (kg ha^{-1})	3,709 a	3,199 a	4,254 a
Dry bean injury (%)	5 a	4 a	2 b
Weed density (plants m^{-2})	0.5 c	1.8 b	2.4 a
Common lambsquarters			
(plants m^{-2})	0.1 c	0.6 b	1.1 a
Toothed spurge (plants m^{-2})	0.1 b	0.2 a	0.1 b
Redroot pigweed(plants m^{-2})	0.1 b	0.2 a	0.2 a

[a] Comparison of means across years on the same horizontal line with the same letter are equivalent according to Fisher's protected LSD at the $\alpha < 0.05$ level.

Results and Discussion

Precipitation following dry bean planting and PRE herbicide application differed among years (Table 1). In 2010, 2011, and 2012 precipitation within 7 d of planting was 55, 18, and 3 mm, respectively, and 8, 42, and 6 mm 8 to14 d after planting, respectively. The 55 mm of precipitation measured in 2010 was the result of several thunderstorms that occurred 6 h and 3 and 4 d after planting. Because of rainfall it was not feasible to add more water with irrigation; hence, in 2010, the main-plot factor of irrigation following planting was omitted. Therefore data collected in 2010 were analyzed separately. Plots were irrigated after planting in 2011 and 2012 and therefore the main-plot factor was included in the data analysis. In all years, irrigation was necessary by mid-July to replenish soil moisture, and irrigation occurred at 10-d intervals until crop maturity in September. In both 2010 and 2011, intense rainfall broke soil aggregates at the soil surface and created a structureless layer with rapid drying resulting in soil crusting. The crust formed above dry bean and some weed seed hampered seedling emergence. Therefore, in 2010 and 2011, all plots were rotary-hoed with a single row of rotary tines when the soil was dry enough to allow tractor operation. At the time of rotary-hoeing both years, dry bean plants were in the crook growth stage and the rotary hoe had to be operated at a shallow depth and slow speed to minimize bean injury.

Differences in growing conditions affected dry bean and weed densities. In 2010, dry bean density was 60% lower than that recorded in 2011, and 2011 density was 20% lower than in 2012 (Table 3). Optimum plant populations for great northern semiupright varieties range from 148,000 to 197,000 plants ha^{-1} (Schwartz et al. 2004). Therefore, in 2010, density was less than the optimum while in 2011 and 2012, density was at or above the optimum. Even though there was a reduction in dry bean density in 2010, seed yields did not differ over the 3-yr period. Research has shown that dry bean plants with a vine or semiupright growth habit have the ability to compensate for stand reduction by spreading into blank areas within and between rows (Schwartz et al. 2004).

Weed density followed a similar trend with 5, 18, and 24 plants m^{-2} recorded in 2010, 2011, and 2012, respectively. The predominant weeds were common lambsquarters, toothed spurge (*Euphorbia dentate* Michx.), and redroot pigweed. Weed counts suggest that among the main weed species, common lambsquarters, which was the first species to emerge, was most affected by growing conditions. Both dry bean and weed densities were affected by soil crusting, which increased as rainfall increased.

Early-season crop injury from herbicides was greater in 2010 and 2011 compared to 2012, regardless of application timing (Table 3). These higher levels of early crop injury are in agreement with more soil crusting observed in those years. Soil crusting has been shown to slow or reduce seedling emergence, extending the time for herbicide uptake and increasing the risk of injury. For example, EPTC injury to dry bean was shown to increase with a delay in seedling emergence caused by deep planting or soil compaction (Wyse et al. 1976). Delays in dry bean emergence increased EPTC absorption which increased crop response.

Irrigation Following Planting. The influence of 13 mm of irrigation water following planting was measured in 2011 and 2012. In 2011, irrigation of a soil that had already received 10 mm of precipitation the previous night reduced dry bean density when compared to not irrigating (Table 4). In contrast, weed density in nontreated areas increased from 37 to 85 plants m^{-2} after irrigation in 2011 and from 28 to 121 plants m^{-2} in 2012 (Table 5).

The theory behind irrigation after planting and PRE application of dimethenamid-P, flumioxazin, halosulfuron, pendimethalin, and *S*-metolachlor

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Table 4. Effect of irrigation after planting (main plots) and preplant tillage (sub plots) on dry bean and weeds near Scottsbluff, NE, in 2010 through 2012.[a]

Irrigation after planting	Seedbed preparation	Dry bean injury 2010[b]	2011	2012	Dry bean density 2010	2011	2012	Dry bean seed yield 2010	2011	2012	Weed density 2010	2011	2012
		%			1,000 plants ha^{-1}			kg ha^{-1}			plants m^{-2}		
Irrigated		—	4 a	1 a	—	157 b	205 a	—	3,154 a	4,540 a	—	2.3 a	3.9 a
Not irrigated		—	4 a	3 a	—	170 a	204 a	—	3,243 a	3,968 b	—	1.1 b	0.8 b
	Double disking	7 a	9 a	0 b	59b	148 b	206 a	3,376 b	3,107 b	4,163 b	0.6 a	1.9 a	2.1 a
	Single disking	6 a	3 b	0 b	61b	153 b	207 a	3,672 a b	3,410 a	4,116 b	0.6 a	1.6 a	3.1 a
	No tillage	2 b	0c	6 a	77 a	190 a	200 b	4,072 a	3,081 b	4,486 a	0.2 a	1.6 a	1.8 b

[a] Means within each column with the same letter are equivalent according to Fisher's protected LSD at the $\alpha < 0.05$ level.

[b] In 2010, 31 mm of precipitation occurred several hours after PRE herbicide application and eliminated the need for irrigation for herbicide incorporation.

was that it would improve herbicide activity by moving the herbicide into the soil. This did not seem to be the case since weed density, and in particular common lambsquarters density, did not differ among irrigated and nonirrigated areas (Table 5). In areas where no herbicide was utilized, irrigation following planting increased weed density.

Seedbed Preparation. The method of seedbed preparation influenced dry bean density, seed yield, and herbicide injury (Table 4). As noted earlier, soil crusting occurred in 2010 and 2011. In both years, dry bean density and crop injury from herbicides were greater where the soil was disked once or twice before planting compared to no-tillage preparation. Disking in combination with precipitation can reduce soil aggregates at the soil surface and result in soil crusting. Preplant tillage and precipitation in 2010 and 2011 were major factors responsible for soil crusting and increased crop injury from herbicides and caused a reduction in dry bean density (Table 4).

In addition, dry bean seed yield in 2010 was reduced 17% by preplant disking compared to no tillage. This was probably the result of stand reduction due to crusting and crop injury from herbicides.

In 2012, when soil crusting was not observed, crop injury from herbicides was greater with no-tillage preparation compared to disking (Table 4). In addition, dry bean plant density was reduced in no-tillage plots compared to disking but the reduction in plant stand did not influence seed yield.

Weed density in 2010 and 2011 was not affected by the method of seedbed preparation; however, in 2012, no-tillage preparation resulted in a reduction in weed density. Common lambsquarters and toothed spurge density in 2012 followed a similar trend for a reduction in density with no-tillage

Table 5. Effect of irrigation after planting and weed control treatments on weed density near Scottsbluff, NE, in 2011 and 2012.[a]

Treatment	Common lambsquarters 2011 Irrigated	2011 Not irrigated	2012 Irrigated	2012 Not irrigated	Total weed density 2011 Irrigated	2011 Not irrigated	2012 Irrigated	2012 Not irrigated
	plants m^{-2}							
Dimethenamid-P	0.8 a	0.6 a	0.5 a	0.2 a	1.7 a	1.0 a	0.9 a	0.3 a
Flumioxazin	0.1 a	0 a	0.1 a	0 a	0.6 a	0.2 a	0.8 a	0.1 a
Halosulfuron	0.3 a	0.2 a	0 a	0 a	1.6 a	0.8 a	2.2 a	0.2 a
Pendimethalin	0.4 a	0.2 a	0.8 a	0.2 a	1.8 a	0.9 a	1.8 a	0.6 a
S-metolachlor	0.9 a	0.8 a	0.2 a	0.4 a	1.4 a	1.6 a	0.5 a	1.0 a
Nontreated	4.9 b	1.1 a	6.9 b	19 a	85 c	3.7 b	12.1 b	2.8 a

[a] Comparison of means within a year on the same horizontal line and within each column with the same letter are equivalent according to Fisher's protected LSD at the $\alpha < 0.05$ level.

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Table 6. Effect of weed control treatment on dry bean and weeds near Scottsbluff, NE, in 2010 through 2012.[a]

Weed control treatment	Weed density			Dry bean seed yield			Dry bean injury			Dry bean density		
	2010	2011	2012	2010	2011	2012	2010	2011	2012	2010	2011	2012
	plants m^{-2}			kg ha^{-1}			%			1,000 plants ha^{-1}		
Dimethenamid-P (PRE)	0.3 bc	1.3 bc	0.6 b	4,160 a	3570 a	4,440 ab	5 b	3 b	3 a	59 c	174 a	206 ab
Flumioxazin (PRE)	0.5 b	0.3 c	0.5 b	3,810 ab	3,280 ab	4,630 a	4 b	4 b	1 b	67 abc	134 b	193 c
Halosulfuron (PRE)	0.4 bc	1.2 bc	1.2 b	4,040 a	3,370 ab	4400 a,b	3 b	7 a	2 ab	73 a	160 a	203 b
Halosulfuron + bentazon (POST)	0.5 b	1.6 b	5.3 c	3,810 ab	3,100 b	4,310 abc	9 a	5 ab	2 ab	67 bc	166 a	206 ab
Imazamox + bentazon (POST)	0. 2c	0.7 bc	1.9 b	3,130b	3,350 ab	3,940 c	8 a	3 b	2 ab	70 abc	169 a	210 a
Pendimethalin (PRE)	0.5 b	1.3 bc	1.2 b	3,,460 ab	3,210 ab	4,140 bc	4 b	4 b	2 ab	66 abc	173 a	205 ab
S-metolachlor (PRE)	0.4 bc	1.6 b	0.7 b	3,870 ab	3,130 b	4,270 ab	4 b	5 ab	3 a	61 c	164 a	205 b
Non-treated	1.2 a	5.9 a	7.5 a	3,400 ab	2,580 c	3,920 c	0 b	0 b	0 bc	63 ab	169 a	208 ab

[a] Means within each column with the same letter are equivalent according to Fisher's protected LSD at the $\alpha < 0.05$ level.

preparation compared to disking (data not shown). The increase in dry bean seed yield in 2012 with no tillage before planting was probably due to the reduction in weed density with no-tillage preparation before planting compared to disking, which increased weed density.

Weed Control. Weed density in nontreated plots averaged 12, 59, and 75 plants m^{-2} in 2010, 2011, and 2012, respectively (Table 6). Common lambsquarters comprised approximately 52% of the weed population followed by redroot pigweed at 16% and toothed spurge at 3%. Each of these weed species was present in the study sites each year. In addition, 10% of the weed population was comprised of annual grasses and 19% as additional broadleaves (data not shown).

A weed density of 1.2 plants m^{-2} in nontreated plots did not result in a reduction in dry bean seed yield in 2010 when compared to areas treated with herbicides (Table 6). However, as weed density increased to 5.9 or 7.5 plants m^{-2} in 2011 and 2012, respectively, dry bean seed yield was reduced in nontreated plots compared to those treated with dimethenamid-P applied PRE.

Dimethenamid-P, flumioxazin, halosulfuron, pendimethalin, and *S*-metolachlor were applied PRE and were equally effective in reducing weed density in 2010 and 2012 compared to the nontreated plots (Table 6). In 2011, flumioxazin was more effective than *S*-metolachlor in reducing weed density while dimethenamid, halosulfuron, and pendimethalin provided similar weed control to flumioxazin.

Early-season dry bean injury from dimethenamid-P, flumioxazin, halosulfuron, pendimethalin, and *S*-metolachlor applied PRE were similar in 2010 and 2012 (Table 6). Halosulfuron applied PRE caused more crop injury than dimethenamid-P, flumioxazin, or pendimethalin in 2011. Early-season crop injury from flumioxazin resulted in a reduction in dry bean density in 2011 and 2012 compared with the other herbicides applied PRE.

In 2011 and 2012, imazamox plus bentazon applied POST reduced weed density to a greater extent than halosulfuron plus bentazon applied POST (Table 6). A similar trend for enhanced weed efficacy from imazamox plus bentazon compared to halosulfuron plus bentazon was also observed in 2011. In 2010, imazamox plus bentazon reduced weed density by 83%, which was greater than that recorded for flumioxazin (58%), pendimethalin (58%), or halosulfuron plus bentazon (58%). In addition to imazamox plus bentazon providing good weed control, the herbicide combination caused early-season crop injury to a greater degree than herbicides applied PRE. Early-season injury from imazamox plus bentazon did not result in a reduction in dry bean density but did result in a reduction in dry bean seed yield in 2010 and 2012 compared to dimethenamid-P or halosulfuron applied PRE. The same trends observed in total weed density from herbicides were also reflected in common lambsquarters, redroot pigweed, and toothed spurge density (data not shown).

Toothed spurge has become problematic in western Nebraska during the past 10 yr. This study demonstrated that toothed spurge density declined with no tillage compared to disking in 2011 and that flumioxazin or halosulfuron PRE reduced toothed spurge density in 2010 and 2012 compared to the nontreated plots (data not shown). Producers

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are moving away from intensive tillage before planting to reduced tillage or no-tillage production systems, and the results of this experiment show that dimethenamid-P, flumioxazin, halosulfuron, pendimethalin, or *S*-metolachlor can be utilized PRE to provide acceptable weed control and crop selectivity. In situations where a PRE herbicide application is not possible due to rainfall or there are weed escapes following herbicides applied PRE, a POST application of imazamox plus bentazon can be utilized for weed control. Several PRE and POST options are available for weed control in dry beans but herbicide sensitivity differs among market classes. Weed control programs in dry beans should use herbicides that have been tested on the variety and under local conditions to reduce the potential for crop injury.

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