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In-Row and Between-Row Interference by Corn Modifies Annual Weed Control by Preemergence Residual Herbicide[1]

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Abstract: The presence of row crops, such as field corn, improves herbicidal control of weeds, but the impact of crop row position on herbicide dose–response relationships for weeds is unknown. At midseason at three site-years in Missouri, total weed cover (WC) was reduced by increasing soil residual herbicide rate in a dose-dependent response and was as much as 20% lower in-row (IR) than between-row (BR). Preemergence atrazine + *S*-metolachlor + clopyralid + flumetsulam at different rates (0×, 0.25×, 0.5×, 0.75×, and 1×, where 1× rate was 2,240 + 1,750 + 210 + 67 g ai/ha, respectively) were applied at planting in field corn to control giant foxtail, the chief weed present, and annual broadleaf weeds, largely common waterhemp. Lower herbicide rates were required to reduce IR WC to the same extent as BR WC, but these rates varied between site-years. At all three site-years, a least squares regression equation adequately described data variability relating corn yield to IR or BR WC (or both) (i.e., $Y = a + bBR^2$, where Y is corn yield in kg/ha, BR is BR WC [%], and a and b are coefficients).

Nomenclature: Atrazine; clopyralid; flumetsulam; glyphosate; *S*-metolachlor; common waterhemp, *Amaranthus rudis* Sauer #[3] ATATA; giant foxtail, *Setaria faberi* (L.) Beauv. # SETFA; corn, *Zea mays* (L.) # ZEAMX, 'Pioneer 33G28'.

Additional index words: Band herbicide application, banding, competition, herbicide, reduced rate herbicide, weed, AMBEL, ATATA, POLPE, POLPY, SETFA, XANST, ZEAMX.

Abbreviations: BR, between-row; IR, in-row; WC, weed cover.

INTRODUCTION

In most weed interference research on corn and other row crops, two weed infestation patterns have been studied in the field: (1) weeds were allowed to grow in an in-row (IR) band and were controlled between-row (BR) or (2) weeds were allowed to grow both IR and BR (Rajcan and Swanton 2001; Zimdahl 1980). Most of these studies evaluated artificial stands of single weed species thinned to known densities, rather than naturally occurring, mixed weed populations. This research focused on crop yield losses caused by weeds, rather than crop suppression of weeds. These limitations have restricted the use of interference research for developing more rational integrated weed management practices based on how weeds can be managed relative to crop rows.

Based on published research on other row crops (Fiebig et al. 1991; Henry and Bauman 1989; Pike et al. 1990; Stoller et al. 1987; Zimdahl 1980), bands of weeds growing only IR were expected to reduce yield more than bands of weeds growing only BR. However, season-long interference by mixed populations of annual weeds growing in bands only IR, only BR, or both IR + BR reduced corn yield differently than expected (Donald and Johnson 2003). Over 4 yr in Missouri, corn yields were ranked as follows in response to weed interference treatments: weed free > IR weedy only > BR weedy only > weedy. Field corn yields of the IR weedy only, BR weedy only, and weedy treatments averaged 76, 63, and 41% of the weed-free treatment (7,280 kg/ha). In 2 of 4 yr, corn yield of the IR weedy treatment exceeded that of the BR weedy treatment, whereas these treatments could not be distinguished from one another statistically in 2 other yr. When weeds grew IR and were controlled BR, corn yielded more, demonstrating that it partially compensated for weed interference better than when weeds were controlled IR but not BR.

This research (Donald and Johnson 2003) suggested

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[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 66044-7050.

that corn either suppressed weed growth more IR than BR or better tolerated weed interference without yield loss. In turn, this observation suggested that soil residual herbicides might suppress weed growth better IR than BR as herbicide rate was reduced because of crop interference. One goal of this research was to determine whether weed ground cover was reduced more IR than BR after a preemergence soil residual herbicide treatment at various rates. The other goal was to characterize the best functional relationship between corn yield and IR and BR WC at midseason after preemergence soil residual herbicide treatment.

MATERIALS AND METHODS

Agronomic Practices. Field corn was planted after soybean [Glycine max (L.) Merr.] at the University of Missouri Bradford Research and Extension Center in central Missouri (38°53′43.5″N, 92°12′37.9″W, 269-m altitude) and at the University of Missouri Greenley Memorial Research Center in northern Missouri (40°0′45″N, 92°12′29″W, 253-m altitude). The Bradford site near Columbia, MO, was on a Mexico silty clay loam (fine, smectitic, mesic Aeric Vertic Epiaqualf), whereas the Greenley site near Novelty, MO, was a Putnam silt loam (fine, montmorillonitic, mesic Vertic Albaqualf). The soil at Bradford had 18 to 20% sand, 46 to 48% silt, 34% clay, 2.9 to 3.4% organic matter, and pH[4] of 5.5 to 5.7, whereas the soil at Greenley had 12 to 16% sand, 52 to 54% silt, 30 to 36% clay, 3 to 3.4% organic matter, and pH of 6.

Dates for field operations, treatments, and measurements are summarized in Table 1. In spring, each site was shallowly disked for seedbed preparation and for facilitating degradation of surface residue. Corn was fertilized with nitrogen, phosphorous, and potassium for a grain yield goal of 10,000 kg/ha, based on soil tests and recommendations of the University of Missouri soil-testing lab. In 2001, N–P–K was broadcast applied before planting at 160:70:90 and 180:60:110 kg/ha at Bradford and Greenley, respectively, and was incorporated by disking. In 2002, N–P–K was broadcast applied at 180:60:110 kg/ha. Glufosinate-resistant ‘Pioneer 33G28’ corn seed[5] were planted 1.3 to 1.9 cm deep in 76-cm rows at 68,000 seed/ha at both sites. Historical weather data were collected at the Bradford farm (Figure 1). Be-

[4] pH are salt pH values that run approximately 0.5 units lower than the customary water pH values.

[5] Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the products, and the use of the name by the USDA implies no approval of the product to the exclusion of others that may also be suitable.

Table 1. Dates for field operations, treatments, or measurements at Bradford in 2001 or Greenley, Missouri, in 2001 and 2002.[a]

Field operation or measurement	Bradford			Greenley					
	Date	DAP	DAE	Date	DAP	DAE	Date	DAP	DAE
Planted crop	April 26, 2001	0	—	April 20, 2001	0	—	May 22, 2002	0	—
Applied atrazine + *S*-metolachlor + Clopyralid + flumetsulam	April 30, 2001	4	-3	April 24, 2001	4	-4	June 4, 2002	13	2
Crop emergence	May 3, 2001	8	0	April 29, 2001	9	0	June 2, 2002	11	0
Applied glufosinate to weeded checks	May 29, 2001	29	26	May 16, 2001	22	18	—	—	—
Measured crop stand	May 23, 2001	27	20	May 16, 2001	26	17	June 14, 2002	23	12
Hoed hand-weeded checks	June 13, 2001	44	41	July 24, 2001	91	87	June 14, 2002	23	12
Rehoed hand-weeded checks	June 14, 2001	45	42	—	—	—	June 25, 2002	34	23
Rehoed hand-weeded checks	—	—	—	—	—	—	July 16, 2002	55	44
Rehoed hand-weeded checks	—	—	—	—	—	—	August 9, 2002	79	68
Photographed ground IR + BR WC	July 16, 2001	77	74	July 11, 2001	78	74	July 2, 2002	41	30
	July 30, 2001	91	88	August 7, 2001	105	101	August 15, 2002	85	74
Harvested grain for yield	September 27, 2001	150	147	November 6, 2001	196	192	September 25, 2002	126	115

[a] Abbreviations: DAP, days after planting; DAE, days after corn emergence; IR, in-row; BR, between-row; WC, weed cover.

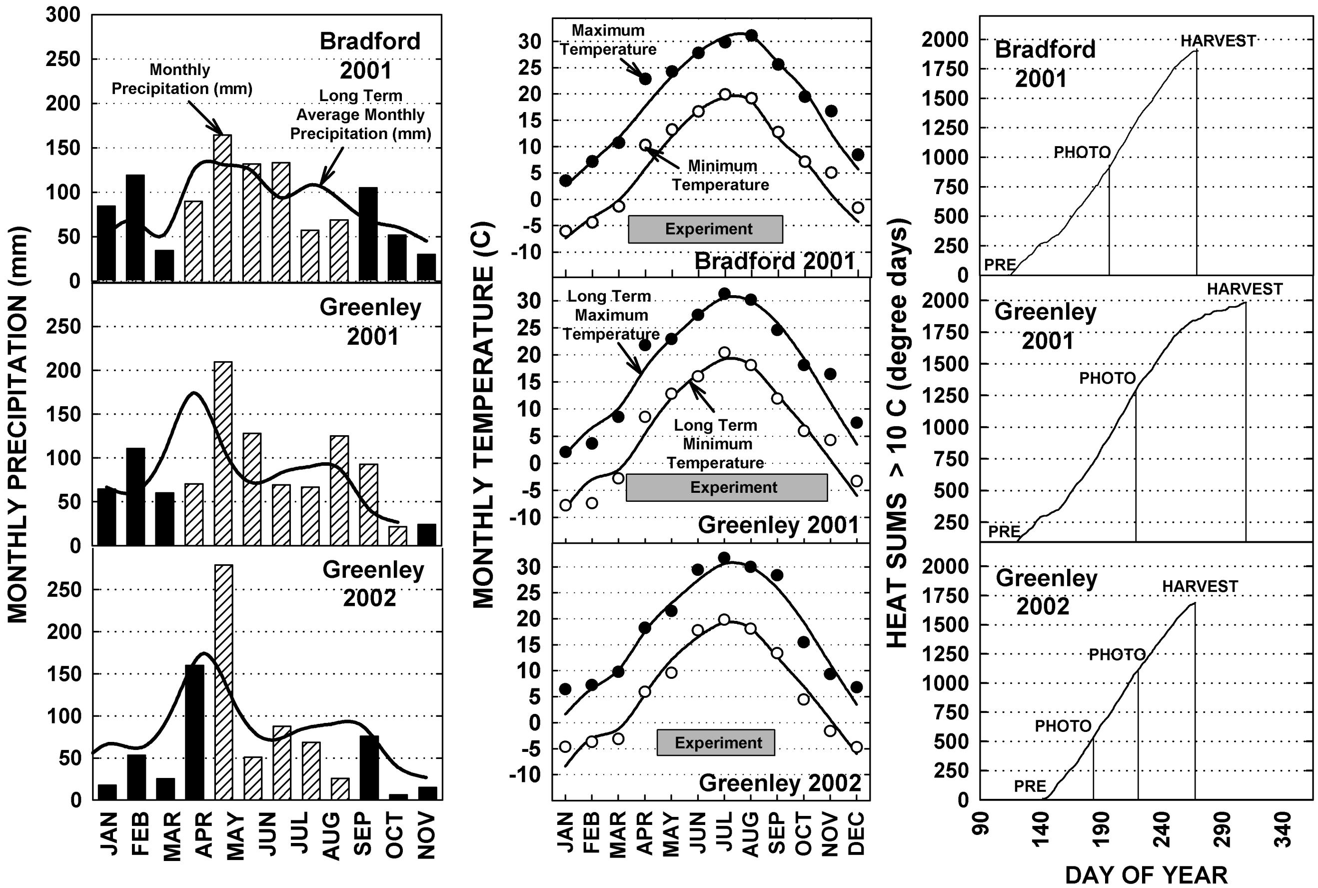

Figure 1. Monthly precipitation during the growing season and for the year are presented in the left panels. The long-term averages were 9 yr (1993 to 2001) for Bradford and 6 yr (1996 to 2001) for Greenley. Monthly average maximum and minimum temperatures and long-term averages are presented in the center panels. Either hatched or gray bars (left panels) or a horizontal line marked "experiment length" (center panel) indicates the duration of the experiments. Growing degree-days after planting, expressed as cumulative heat sums >10 C, are presented in the right panels. Significant events are marked as PRE (preemergence herbicide application), PHOTO (photographs taken), and HARVEST.

cause weather data were very incomplete at Bradford in 1995 and 2001, data from nearby weather stations were substituted for those years. Weather data were from Sanborn Experimental Field and University of Missouri South Farm in 1995 and 2001, respectively. For Greenley, a shorter continuous weather record was used. Heat sums were calculated using a base temperature of 10 C (Ruiz et al. 1998) (Figure 1).

Giant foxtail was the chief weed present at both sites. At Bradford, common waterhemp was the chief broadleaf weed present, followed by Pennsylvania smartweed (*Polygonum pensylvanicum* L.) and common ragweed (*Ambrosia artemisiifolia* L.). At Greenley, common waterhemp was the chief broadleaf weed present, followed by common cocklebur (*Xanthium strumarium* L.), ladysthumb smartweed (*Polygonum persicaria* L.), Pennsylvania smartweed, and velvetleaf (*Abutilon theophrasti* Medik.).

Herbicide Treatments. Atrazine + *S*-metolachlor + clopyralid + flumetsulam were broadcast applied preemergence at 0× (weedy check), 0.25×, 0.5×, 0.75×, and 1× rates (Table 1). The 1× rate of atrazine + *S*-metolachlor + clopyralid + flumetsulam[6] was 2,240 + 1,750 + 210 + 67 g ai/ha, respectively. Treatments were arranged in a randomized complete block design with four or five blocks (Gomez and Gomez 1984; Hoshmand 1994). Individual plots measured 3 by 13.7 m at Bradford and 3 by 9.1 m at Greenley.

Herbicides were broadcast applied with a backpack sprayer at a volume of 168 to 170 L/ha through flat-fan nozzle tips[7] spaced 76.2 cm apart on the spray boom and using compressed CO_2 at 193 kPa as a propellant. The ground speed was maintained at 1.6 km/h using a metronome.

Seedbed preparation killed the weeds present before

[6] Bicep II Magnum (atrazine + *S*-metolachlor), Syngenta, Greensboro, NC 27419-8300. Hornet (clopyralid + flumetsulam), Dow AgroSciences LLC, Indianapolis, IN 46268-3033.

[7] Teejet 6501 flat-fan nozzle tip, Spraying Systems Co., North Avenue, Wheaton, IL 60188.

planting. Weeded checks were created using postemergence glufosinate at 280 g ai/ha, followed by hoeing and hand-pulling weeds several times during the growing season (Table 1). To avoid damaging the corn, the hoeing and hand-pulling were stopped at corn silking. Although these hand-weeded plots were not weed free at harvest, weeds emerging after silking and canopy closure do not reduce corn grain yield (Bedmar et al. 1999; Hall et al. 1992).

Measurements. Corn stand was determined by counting all plants in the two center rows of four-row plots (Table 1). After cutting borders at either end of the plots, corn was combine-harvested from the two center rows in an area measuring 1.5 by 10.6 m and 1.5 by 8.2 m at Bradford and Greenley, respectively, and grain yields were adjusted to 15% moisture content.

WC of giant foxtail, broadleaf weeds, and total weeds (giant foxtail + broadleaf weeds) was measured from photographs taken IR and BR to document the effect of the treatments on weeds, rather than to predict crop grain yield loss (Knezevic et al. 1994, 1995; Ngouajio et al. 1999a, 1999b, 1999c). Before taking photographs after silking (Table 1), corn foliage overhanging the IR and BR zones was pulled back with 1-m^2 wooden frame panels covered with dark cloth, and an orange dowel was extended at 90° 19 cm out from the crop row at the soil surface toward the row middle to indicate the IR zone width in the photographs. Four photographs per zone per plot were taken vertically toward the soil surface with a digital camera[8] at a height of 132 cm. Each photograph corresponded to 1.1 m^2 at the soil surface based on photographs of a 30- by 30-cm orange calibration plate. Maximum weed canopy height was measured for each photograph. Photographs (640 by 512 pixels per photograph in 2001 and 1,600 by 1,200 pixels per photograph in 2002) were saved as JPG files for image analysis. Image analysis software[9] was used to crop BR and IR zones and automatically superimpose a 20- by 20-pixel grid over each cropped photograph. The number of grid intersections with either giant foxtail or broadleaf WC categories were counted in each photograph. Giant foxtail WC, broadleaf WC, and total WC were calculated as follows:

$$WC = (n/N)100 \qquad [1]$$

where WC = giant foxtail, broadleaf, or total (%), n = number of grid line intersections in each category, N = total number of grid line intersections per cropped photograph.

WC measurements are the average of 4 photographs per plot for each plant category in either the IR or BR zones.

Statistical Analysis. For the IR and BR zones separately at each site, the giant foxtail, broadleaf, and total WC, the dependent variables, were regressed vs. relative herbicide rate, the independent variable, using software.[10] The simple equation option of the software was used to screen the most parsimonious linear and nonlinear equations (Helsel and Hirsch 1992; Hoshmand 1994). Best least squares regression equations were selected after ranking equations based on degree of freedom-adjusted r^2, acceptable goodness of fit, and examination of residual scatter vs. relative herbicide rate.

For each site-year, yield data also were subjected to response surface regression (Myers and Montgomery 2002). Software[11] was used to regress grain yield, the dependent variable, on IR WC or BR WC (or both) at midseason, the independent variables. Polynomial equations were initially fitted using means of the dependent variables, and the resulting polynomial equations were sorted by adjusted r^2 (Table 2). Because F values for all equations were significant (P = 0.05 or less), simplest parsimonious equations were selected that had both high adjusted r^2 and coefficients for X or Y (or both) terms, which differed from zero. Equation suitability was evaluated based on adjusted r^2 and visual inspection of residual scatter vs. the independent variables. After a suitable equation was selected, the regression analysis was rerun using all data instead of means, and results were presented using graphing software.[12]

RESULTS AND DISCUSSION

Weed Cover. By midseason, corn interference suppressed IR WC more than BR WC (Figure 2). In the weedy check at Bradford, the midseason BR and IR WC were 78 (±7)% (mean [±SE]) and 63 (±6)% of the ground cover, respectively. At Greenley, BR and IR WC were 73 (±2)% and 53 (±9)% in 2001 and 86 (±5)% and 81 (±2)% in 2002, respectively.

Most of the total WC was giant foxtail. At midseason, BR and IR giant foxtail cover were 63 and 62% of the total weed cover (WC) at Bradford, 79 and 81% at

[8] Olympus D-620 L digital camera in 2001 and Olympus C4040 zoom digital camera in 2002, Olympus America Inc., Melville, NY 11747-3157.

[9] Sigma Scan Pro version 5, SPSS Inc., Chicago, IL 60606-6412.

[10] Table Curve 2D version 5, SPSS Inc., Chicago, IL 60606-6412.

[11] Table Curve 3D version 4, SYSTAT Software Inc., Richmond, CA 94804-2028.

[12] SigmaPlot 2000, SPSS Inc., Chicago, IL 60606-6412.

Table 2. Equations that were tested to relate corn yield (Z) in kg/ha to IR WC (X) and BR WC (Y).[a]

Equation[b]							
Z =	a	+ bX		+ dY			(1)
Z =	a	+ bX		+ dY	+ eY^2		(2)
Z =	a	+ bX			+ eY^2		(3)
Z =	a	+ bX	+ cX^2	+ dY			(4)
Z =	a	+ bX	+ cX^2	+ dY	+ eY^2		(5)
Z =	a		+ cX^2	+ dY			(6)
Z =	a		+ cX^2	+ dY	+ eY^2		(7)
Z =	a		+ cX^2		+ eY^2		(8)
(Equations 1–8)						+ fXY	(9–16)
Z =	a	+ bX					(17)
Z =	a	+ bX	+ cX^2				(18)
Z =	a		+ cX^2				(19)
Z =	a			+ dY			(20)
Z =	a			+ dY	+ eY^2		(21)
Z =	a				+ eY^2		(22)
(Equations 17–22)						+ fXY	(23)

[a] Abbreviations: IR, in-row; BR, between-row; WC, weed cover.
[b] Z is corn yield (kg/ha), X is IR WC (%), and Y is BR WC (%).

Greenley in 2001, and 83 and 86% at Greenley in 2002, respectively. Thus, corn interference did not influence giant foxtail or broadleaf WC as a percentage of total WC in relation to row position.

The null hypothesis was that total WC would decrease as a function of increasing soil residual herbicide rate, independently of row position. Thus, the IR herbicide dose–response curve should have equaled the BR herbicide dose–response curve. As expected, total WC decreased as relative herbicide rate increased, but the decrease in total WC was greater IR than BR at all herbicide rates at all site-years, presumably as a result of corn interference (Figure 2 and Table 3). Consequently, lower soil residual herbicide rates were required to reduce IR total WC to the same extent as BR total WC at all site-years. For example, the BR rates needed to reduce BR total WC to a value of 40% were greater than the IR rates needed to reduce IR total WC to a value of

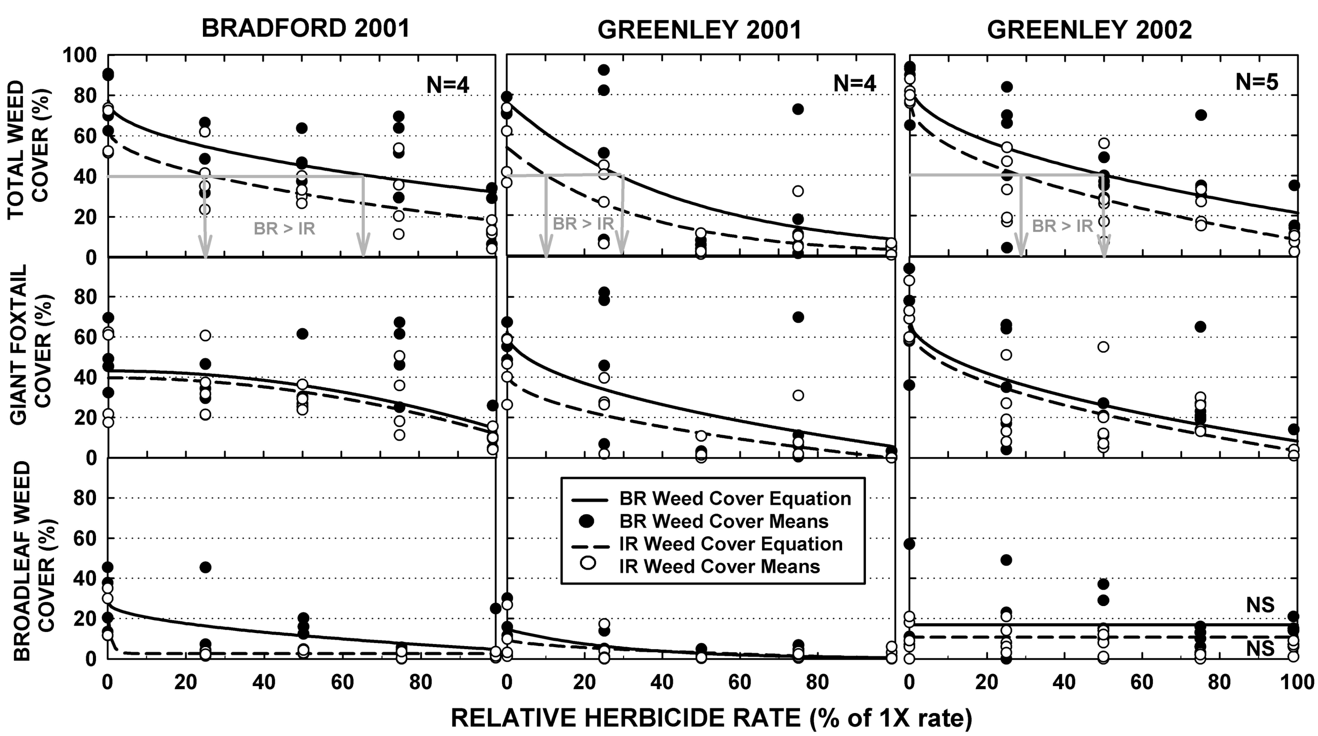

Figure 2. Regression equations and data for giant foxtail, broadleaf, and total weed cover (%) vs. relative herbicide rate (%) at between-row (BR) and in-row (IR) positions at midseason at Bradford in 2001 and Greenley in 2001 and 2002. See Table 1 and Figure 1 for dates of photography and Table 3 for regression equations.

Table 3. Equations of total, giant foxtail, and broadleaf weed cover (%) vs. relative herbicide rate (% of 1× rate) at midseason for in-row and between-row positions for three site-years. All regression equations were significant at P = 0.001 or less, and coefficients (±SE) and adjusted coefficients of determination (r^2) are presented.

Site-year	Position	Weed cover category	Equation[a]	r^2
Bradford, 2001	Between row	Total weeds	$Y = 77.35 (\pm 7.42) - 4.51 (\pm 1.05) \times X^{0.5}$	0.45
		Giant foxtail	$Y = 43.01 (\pm 4.14) - 0.0029 (\pm 0.0008) \times X^2$	0.35
		Broadleaf weeds	$Y = 28.07 (\pm 5.50) - 2.35 (\pm 0.78) \times X^{0.5}$	0.26
	In row	Total weeds	$Y = 63.63 (\pm 5.62) - 4.56 (\pm 0.79) \times X^{0.5}$	0.61
		Giant foxtail	$Y = 39.59 (\pm 4.69) - 0.0028 (\pm 0.0009) \times X^2$	0.28
		Broadleaf weeds	$Y = 2.60 (\pm 1.30) + 19.43 (+2.91) \times \exp(X)$	0.68
Greenley, 2001	Between row	Total weeds	$Y = 76.34 (\pm 11.97) \times \exp[-X/44.18 (\pm 13.71)]$	0.47
		Giant foxtail	$Y = 62.58 (\pm 11.32) - 5.72 (\pm 1.64) \times X^{0.5}$	0.34
		Broadleaf weeds	$Y = 14.71 (\pm 2.85) \times \exp[-X/29.38 (\pm 11.93)]$	0.37
	In row	Total weeds	$Y = 53.77 (\pm 6.43) \times \exp[-X/33.66 (\pm 8.18)]$	0.64
		Giant foxtail	$Y = 42.45 (\pm 5.42) - 4.28 (\pm 0.79) \times X^{0.5}$	0.59
		Broadleaf weeds	$Y = 9.89 (\pm 2.78) - 0.98 (\pm 0.40) \times X^{0.5}$	0.16
Greenley, 2002	Between row	Total weeds	$Y = 85.93 (\pm 7.23) - 6.45 (\pm 1.02) \times X^{0.5}$	0.60
		Giant foxtail	$Y = 69.40 (\pm 7.76) - 6.12 (\pm 1.10) \times X^{0.5}$	0.54
		Broadleaf weeds	$Y = 16.89 (\pm 5.18)$	—
	In row	Total weeds	$Y = 76.74 (\pm 4.96) - 6.88 (\pm 0.70) \times X^{0.5}$	0.79
		Giant foxtail	$Y = 65.22 (\pm 5.87) - 6.18 (\pm 0.83) \times X^{0.5}$	0.68
		Broadleaf weeds	$Y = 10.73 (\pm 2.02)$	—

[a] Y is weed cover (%) and X is relative herbicide rate (%).

40% (Figure 1). However, the BR and IR rates required for this varied between site-years (light gray arrows, Figure 2), presumably because of weather differences (Figure 1). Greater rainfall through July at Bradford than at Greenley in either year may have favored weed recovery or emergence of new cohorts of weeds by midseason.

At all site-years, differences between equations relating either BR or IR total WC to herbicide rate were greater than for either giant foxtail or broadleaf WC, the component parts of total WC (Figure 2 and Table 3). Differences between BR and IR total WC were largely due to differences in broadleaf WC at Bradford in 2001 but were due to differences in giant foxtail WC at Greenley in 2001. At Greenley in 2002, differences between BR and IR total WC were likely due to differences in both giant foxtail and broadleaf WC.

Although the reasons for different responses between BR and IR total WC and herbicide rate between site-years cannot be determined from this experiment (Figure 2), some potential causes can be eliminated. Because rainfall after treatment was timely (Figure 1) and soil types were similar between sites, herbicide availability in soil solution should not have limited control of germinating weeds. Reportedly, higher preemergence herbicide rates were needed to control weeds from dense than from sparse weed seed banks (Taylor and Hartzler 2000). However, it is unlikely that seed bank density or weed emergence would be affected by crop row position. When photographed early (Greenley 2002 only, Figure 1 and Table 1), BR and IR total WC were equal over the range of herbicide rates (data not presented). Apparently, herbicide controlled BR and IR WC equally well over a range of herbicide rates early in the growing season. But, by midseason, differences in BR and IR total WC developed due to the interaction of herbicide rate and crop suppression of emerging and surviving IR and BR weeds.

Corn Yield vs. IR and BR WC Emerging After Herbicide Treatment. At all site-years, yield of the hand-weeded check was indistinguishable from the 1× broadcast treatment. At Bradford in 2001, corn grain yield in the weedy check was 3,830 (±2,330) kg/ha (mean [±SD]), which was 42% of the grain yield for the broadcast 1× rate (9,140 [±1,640] kg/ha) and 46% of the hand-weeded check (8,410 [±1,060] kg/ha). At Greenley in 2001, corn yield in the weedy check was 3,580 (±2,110) kg/ha, which was 56% of the grain yield for the broadcast 1× rate (6,360 [±880] kg/ha) and 51% of that for the hand-weeded check (6,990 [±76] kg/ha). At Greenley in 2002, corn yield in the weedy check was 2,350 (±600) kg/ha, which was 26% of the grain yield for the broadcast 1× rate (9,050 [±330] kg/ha) and 29% of that for the weed-free check (8,220 [±540] kg/ha). These yield differences were not due to differences in corn stand because stands were similar at all site-years. Greater corn yields may be due to the greater, more favorable rainfall distribution at Bradford in 2001 than at Greenley in either year (Figures 1 and 3).

Corn yield was regressed on midseason IR and BR WC created by herbicide treatments (Figure 3 and Table 4). The null hypothesis was that both IR and BR total

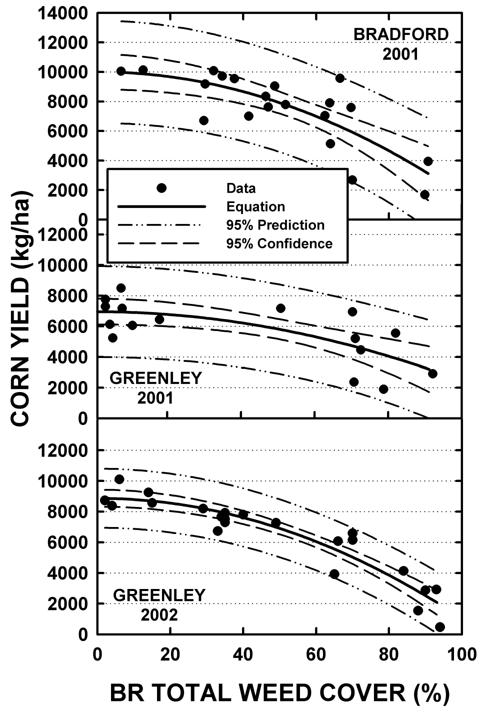

Figure 3. Corn yield (Y, kg/ha) vs. between-row (BR) weed cover (X, %) at midseason at Bradford in 2001 and Greenley in 2001 and 2002. Observations (solid circles), fitted regressions equations (solid line), 95% confidence intervals (dashed lines), and 95% prediction intervals (dotted line) are presented. See Table 4 for regression equations.

WC were required to best model corn yield loss. Indeed, equations with both IR and BR total WC accounted for most corn yield variability (Table 4). However, different equations were required for each site-year. Nevertheless, the most parsimonious (i.e., those with only one independent variable, BR^2 total WC) accounted for almost as much data variability in corn yield as did equations with both IR and BR total WC (Figure 3 and Table 4). In 2 of 3 yr, equations relating corn yield to only IR total WC accounted for much less equation variability than equations with either BR total WC alone or BR + IR total WC. At Greenley in 2002, the three equations (IR total WC alone, BR total WC alone, and IR + BR total WC) described corn yield variability similarly.

Usually, herbicides are broadcast applied, independently of crop row position. However, weeds can be managed differently in the IR and BR zones. When farm labor was more plentiful in the 1950s and 1960s and farmers wished to reduce herbicide input costs, IR weeds were controlled with banded herbicides and BR weeds were controlled by field cultivation (Schroder et al. 1984). Other mechanical techniques, such as close BR mowing, can substitute for cultivation without yield loss in corn and soybeans (Donald et al. 2001). In the Midwest, corn producers now rely on herbicides to manage weeds, rather than cultivation (Anonymous 2002; Missouri Agricultural Statistics Service 2001; Rikoon et al. 1996). Recent farmer surveys established that most Missouri farmers rejected herbicide banding followed by field cultivation as a best management strategy for reducing herbicide contamination of water (Rikoon et al. 1996). The present research shows that IR total WC was reduced more than BR total WC by herbicides, presumably because corn interference helped suppress IR total WC (Figure 2). Previous research established that bands of weeds growing between corn rows reduced yields more than did bands of weeds growing in crop rows (Donald and Johnson 2003). These two observations suggest new ways to apply herbicides to reduce preemergence residual herbicide use: banding lower herbicide rates IR than BR. Because lower herbicide rates are required IR than BR to consistently control weeds, it may be possible to reduce total herbicide use per unit area using differential rate applications without reducing yield or economic returns.

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Table 4. Corn yield (kg/ha) (Z) as a function of both in-row (IR) weed cover (%) + between-row (BR) weed cover (%) or either independent variable separately (Y). All regression equations were significant at P = 0.001 or less, IR and BR coefficients (±SE) and degree of freedom-adjusted coefficients of determination (r^2) are presented.

Site-year	Independent variables		Equations for corn yield (kg/ha) vs. IR or BR weed cover (or both) (%)	r^2
Bradford 2001	IR	BR	$Z = 9976.71\ (\pm 535.43) + 1.11\ (\pm 0.56) \times IR^2 - 2.03\ (\pm 0.52) \times IR \times BR$	0.61
	IR	—	$Y = 10292.98\ (\pm 897.75) - 77.55\ (\pm 22.03) \times IR$	0.34
	—	BR	$Y = 10001.49\ (\pm 566.68) - 0.84\ (\pm 0.15) \times BR^2$	0.58
Greenley 2001	IR	BR	$Z = 6373.59\ (\pm 469.27) + 139.70\ (\pm 76.20) \times IR - 2.40\ (\pm 0.92) \times IR \times BR$	0.54
	IR	—	$Y = 7051.21\ (\pm 450.74) - 55.17\ (\pm 14.69) \times IR$	0.39
	—	BR	$Y = 6958.87\ (\pm 399.15) - 0.45\ (\pm 0.11) \times BR^2$	0.45
Greenley 2002	IR	BR	$Z = 9888.67\ (\pm 290.96) - 59.45\ (\pm 11.58) \times IR - 29.60\ (\pm 10.71) \times BR$	0.92
	IR	—	$Y = 9454.92\ (\pm 281.07) - 87.52\ (\pm 6.39) \times IR$	0.89
	—	BR	$Y = 8867.15\ (\pm 265.69) - 0.78\ (\pm 0.06) \times BR^2$	0.87

LITERATURE CITED

Anonymous. 2002. Missouri Crop and Weather Report. U.S. Department of Agriculture, National Agricultural Statistics Service. 37 p.

Bedmar, F., P. Manetti, and G. Monterubbianesi. 1999. Determination of the critical period of weed control in corn using a thermal basis. Pesqui. Agropecu. Bras. Brasilia 34:187–193.

Donald, W. W. and W. G. Johnson. 2003. Interference effects of weed-infested bands in or between crop rows on field corn (*Zea mays*) yield. Weed Technol. 17:755–763.

Donald, W. W., N. R. Kitchen, and K. A. Sudduth. 2001. Between-row mowing + banded herbicide to control annual weeds and reduce herbicide use in no-till soybean (*Glycine max*) and corn (*Zea mays*). Weed Technol. 15:576–584.

Fiebig, W. W., D. G. Shilling, and D. A. Knauft. 1991. Peanut genotype response to interference from common cocklebur. Crop Sci. 31:1289–1292.

Gomez, K. A. and A. A. Gomez. 1984. Statistical Procedures for Agricultural Research. 2nd ed. New York: J. Wiley. Pp. 20–30, 241–247, 316–356.

Hall, M. R., C. J. Swanton, and G. W. Anderson. 1992. The critical period of weed control in grain corn (*Zea mays*). Weed Sci. 40:441–447.

Helsel, D. R. and R. M. Hirsch. 1992. Statistical Methods in Water Resources. New York: Elsevier. Pp. 157–208, Appendix A.

Henry, W. T. and T. T. Bauman. 1989. Interference between soybeans (*Glycine max*) and common cocklebur (*Xanthium strumarium*) under Indiana field conditions. Weed Sci. 37:753–760.

Hoshmand, A. R. 1994. Experimental Research Design and Analysis. A Practical Approach for Agricultural and Natural Sciences. Boca Raton, FL: CRC. Pp. 297–345.

Knezevic, S. Z., S. F. Weise, and C. J. Swanton. 1994. Interference of redroot pigweed (*Amaranthus retroflexus*) in corn (*Zea mays*). Weed Sci. 42:568–573.

Knezevic, S. Z., S. F. Weiss, and C. J. Swanton. 1995. Comparison of empirical models depicting density of *Amaranthus retroflexus* L. and relative leaf area as predictors of yield loss in maize (*Zea mays* L.). Weed Res. 35:207–214.

Missouri Agricultural Statistics Service. 2001. 2001 Missouri Farm Facts. Jefferson City, MO: Missouri Department of Agriculture/Washington, DC: U.S. Department of Agriculture, National Agricultural Statistics Service. P. 39.

Myers, R. H. and D. C. Montgomery. 2002. Response Surface Methodology. Process and Product Optimization Using Designed Experiments. 2nd ed. New York: J. Wiley. 798 p.

Ngouajio, M., C. Lemieux, and G. D. Leroux. 1999a. Prediction of corn (*Zea mays*) yield loss from early observations of the relative leaf area and the relative leaf cover of weeds. Weed Sci. 47:297–304.

Ngouajio, M., G. D. Leroux, and C. Lemieux. 1999b. Influence of images recording height and crop growth stage on leaf cover estimates and their performance in yield prediction models. Crop Prot. 18:501–508.

Ngouajio, M., G. D. Leroux, and C. Lemieux. 1999c. A flexible sigmoidal model relating crop yield to weed relative leaf cover and its comparison with nested models. Weed Res. 39:329–343.

Pike, D. R., E. W. Stoller, and L. M. Wax. 1990. Modeling soybean growth and canopy apportionment in weed-soybean (*Glycine max*) competition. Weed Sci. 38:522–527.

Rajcan, I. and C. J. Swanton. 2001. Understanding maize-weed competition: resource competition, light quality and the whole plant. Field Crops Res. 71:139–150.

Rikoon, J. S., D. H. Constance, and S. Galetta. 1996. Factors affecting farmer's use and rejection of banded pesticide applications. J. Soil Water Conserv. 51:322–329.

Ruiz, J. A., J. J. Sanchez, and M. M. Goodman. 1998. Base temperature and heat unit requirement of 49 Mexican maize races. Maydica 43:277–282.

Schroder, D., J. C. Hatley, and R. M. Finley. 1984. The contribution of herbicides and other technologies to corn production in the corn belt region, 1964 to 1979. N. Cent. J. Agric. Econ. 6:95–104.

Stoller, E. W., S. K. Harrison, L. M. Wax, E. E. Regnier, and E. D. Nafziger. 1987. Weed interference in soybeans (*Glycine max*). Rev. Weed Sci. 3:155–182.

Taylor, K. L. and R. G. Hartzler. 2000. Effect of seed bank augmentation on herbicide efficacy. Weed Technol. 14:261–267.

Zimdahl, R. L. 1980. Weed-Crop Competition, a Review. Corvallis, OR: Oregon State University. Pp. 46– 49, 84–85.