Practical Changes to Single-Boom Sprayers for Zone Herbicide Application[1]

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Abstract: Reduced-rate zone herbicide application (ZHA) consists of banding reduced herbicide rates between crop rows full broadcast registered rate, 1 X) and banding much reduced herbicide rates over crop rows 1 X). The objective of this research was to compare the mechanically complicated dual-boom ZHA sprayer with a much simpler, single-boom ZHA sprayer for controlling giant foxtail and common waterhemp in field corn in 2003 and 2004 in Missouri. The dual-boom ZHA sprayer employed two different herbicide solutions, which were propelled through two booms on separate sprayer systems to apply different herbicide rates over in-row and between-row areas while maintaining similar carrier volumes and coverage through two booms. In contrast, the single-boom ZHA sprayer is a mechanically simpler system in which both herbicide rates and carrier volumes were varied across one boom over in-row (IR) and between-row (BR) areas. In single-boom ZHA, two different nozzle tips were alternated on one boom over in-row and between-row areas, the number of nozzles per boom was doubled, and the distance between nozzles was halved compared with a conventional sprayer boom. In a 2-yr study, these different ZHA sprayers were used to apply preemergence atrazine + S-metolachlor between and over crop rows at various reduced rates (1 X = 2,240 + 1,750 g ai/ha, respectively). Among all single- and dual-boom ZHA sprayer treatments and the weed-free checks, corn yields and in-row total weed cover were statistically indistinguishable for both years and for between-row total weed cover in 1 of 2 yr. In both years, a single-boom ZHA system prevented yield loss from competing weeds as effectively as the dual-boom ZHA system. The new single-boom ZHA system is a mechanically simple, inexpensive, generic alternative for reducing herbicide rates and lowering input costs.

Nomenclature: Atrazine; S-metolachlor; common waterhemp, *Amaranthus rudis* Sauer #[3] AMATA; giant foxtail, *Setaria faberii (L.)* Beauv. # SETFA; corn, *Zea mays* L., 'Pioneer 33G28' and 'Pioneer 34M92'

Additional index words: Band application, banding, chloroacetamide, reduced rate, triazine, weed.

Abbreviations: BR, between-row; IR, in-row; WC, weed cover; ZHA, zone herbicide application.

INTRODUCTION

For more than 15 yr, weed scientists have examined the weed control efficacy of broadcast, PRE, soil-residual herbicides, such as triazine and chloroacetamide herbicides, when applied at reduced rates in corn (Buhler et al. 1995; Bussan and Boerboom 2001; Hamill and Zhang 1995; Lin et al. 1995; O'Sullivan and Bouw 1993; O'Sullivan and Bouw 1997; Zhang et al. 2000; Zoschke 1994). This research was motivated by a desire to reduce water contamination by herbicides and to improve the profitability (i.e., $ net returns) and economic efficiency (i.e., $/kg herbicide inputs used) of field crop production. If weed control and yields are not reduced, management practices that decrease farmers' input costs by reducing herbicide rates can help improve profitability. For some herbicides, soil types, and environments, soil residual herbicides at certain reduced rates controlled targeted weeds so that yields were no different than for maximum broadcast registered (1x) rates (Buhler et al. 1995; Bussan and Boerboom 2001; Doyle and Stypa 2004; Hamill and Zhang 1995; Lin et al. 1995; O'Sullivan and Bouw 1993; O'Sullivan and Bouw 1997; Zhang et al. 2000; Zoschke 1994).

Previous research has documented the feasibility and potential economic advantages of reduced-rate ZHA over reduced-rate broadcast herbicide application for annual weed control with a preemergence herbicide mixture in corn (Donald et al. 2004b). Reduced-rate ZHA

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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 `'SSA, 810 East 10th Street, Lawrence, KS 66044-8897.

consisted of banding reduced herbicide rates between corn rows 1 X) and banding much reduced herbicide rates over crop rows (≤ 1X). In 2 of 3 yr, corn grain yields for the highest yielding reduced-rate ZHA and the 1X broadcast treatments were statistically indistinguishable. Net returns for the highest yielding ZHA treatment were statistically indistinguishable from the 1X broadcast treatment in all 3 site-yr (Donald et al. 2004b). When averaged over 3 site-yr, the best ZHA treatment reduced the amount of herbicide applied to 53% of the 1X rate.

In the above-mentioned study, the herbicide mixture was applied at different rates over and between corn rows using two offset tandem booms connected to separate spray tanks containing different concentrations of herbicides (Donald et al. 2004b). Identical even nozzles were used on tandem booms to ensure that the carrier volume and spraying parameters were the same both over and between rows. This dual-boom ZHA system also ensured excellent control of separate herbicide rates over and between crop rows for research purposes. However, dual-boom herbicide sprayers for ZHA are complicated, expensive, and double sprayer-equipment costs for farmers (i.e., dual-boom ZHA sprayers have two separate but coupled booms, hydraulic systems, spray tanks, etc.).

As an alternative to a dual-boom ZHA sprayer, farmers could modify existing ground sprayers for single-boom ZHA.[4] Compared with conventional hydraulic herbicide spraying, the only changes required to apply different IR and BR herbicide rates through a single boom sprayer would be to (1) double the number of nozzles, (2) halve the distance between nozzles, and (3) alternate two different types of even nozzles on the boom. The single-boom ZHA sprayer is mechanically simple and requires only one spray tank for herbicides. As discussed in the Materials and Methods section on sprayer calibration, different IR and BR herbicide rates are regulated by the choice of both herbicide concentration in the spray tank and the choice of different IR and BR even nozzles. Sprayer calibration for single-boom ZHA requires knowledge of carrier volume output ratios for various combinations of IR and BR even nozzle spray tips. However, it is only slightly different and no more complicated than calibration of conventional broadcast sprayers. In single-boom ZHA, boom height must be adjusted to ensure limited IR and BR spray pattern overlap.

The objective of this research was to test the null hypothesis that reduced-rate PRE residual herbicides applied by dual- and single-boom ZHA were statistically indistinguishable from one another or the weed-free check based on corn grain yield and annual weed control as measured by weed cover. The alternative hypothesis was that reduced-rate ZHA with a dual-boom system would be superior to a single-boom system based on these two variables.

MATERIALS AND METHODS

Agronomic Practices. The study was conducted at the University of Missouri's Greenley Memorial Research Center in northern Missouri near Novelty (40°0'45"N, 92°12'29"W; 254 m altitude) in 2003 and 2004. The soil was a Putnam silt loam (fine, montmorillonitic, mesic Vertic Albaqualf) with 12 to 16% sand, 52 to 54% silt, 30 to 36% clay; 3 to 3.4% organic matter; and a pHs (salt pH) of 6. Salt pH values are approximately 0.5 units lower than water pH values.

Dates for field operations, treatments, and measurements are presented (Table 1; Figure 1). The sites were harrowed and field cultivated in spring before planting. For a corn grain yield goal of 10,400 kg/ha in both years, fertilizer N–P–K at 179-90-135 kg/ha was broadcast and incorporated with a disk-harrow before planting. Glufosinate-resistant corn seed (Pioneer 33G28' in 2003 and 'Pioneer 34M92' in 2004)[5] were planted 1.5 to 2.5 cm deep in 76-cm rows at 76,600 seed/ha. Glufosinate-resistant corn seed was chosen to facilitate creation of weed-free checks.

Historical weather data were collected at the Greenley Research Center between 1996 and 2002. Heat sums for corn were calculated from planting until harvest using a base temperature of 10 C (Ruiz et al. 1998).

In both years, giant foxtail was the dominant weed present. Common waterhemp was the most abundant broadleaf weed, with sparse infestations of common cocklebur (*Xanthium strumarium* L. # XANST), common ragweed (*Ambrosia artemisiifolia* L. # AMBEL), and velvetleaf (*Abutilon theophrasti* Medicus # ABUTH).

Weed-free checks were created with postemergence glufosinate at 280 g ai/ha followed by respraying (2004 only), hoeing, and hand-pulling weeds until corn silking (Table 1; Figure 1). Weeds emerging after silking and canopy closure do not reduce corn grain yields (Bedmar et al. 1999; Hall et al. 1992).

[4] Rhett Hunziker, Rural Route 1, Box 193, Knox City, MO 63446, personal communication in 2002.

5/ Mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

Table 1. Dates for field operations, treatments, or measurements at the Greenley Research Center near Novelty, MO, in 2003 and 2004.[a]

Field operation or measurement	2003 Date mo/day	2003 DAP	2004 Date mo/day	2004 DAP
Crop planted	5/22	0	5/6	0
Preemergence atrazine + *S*-metolachlor application	5/28	6	5/10	4
Crop emergence	5/29	7	5/12	6
Crop stand measured	6/16	25	6/3	28
Weed-free check only:				
Glufosinate application	6/16	25	6/3	28
Weeds hoed and hand pulled	7/2	41	6/24	49
Glufosinate application	7/31	70	—	—
Weed cover photographed	7/2	71	6/29	54
Corn harvested	10/29	160	9/22	139

[a] Abbreviations: mo, month; DAP, days after planting.

Herbicide Treatments. PRE atrazine + S-metolachlor were applied either by a single- or a dual-boom ZHA sprayer at reduced rates (1 X normal rate = 2,240 + 1,750 g ai/ha) (Table 1; Figure 1). For dual-boom ZHA treatments, relative herbicide rates were 0.25X, 0.35X, and 0.5 X for IR treatments and 1X for all accompanying BR treatments. For the corresponding three single-boom ZHA treatments, relative herbicide rates for combinations of IR and BR rates were 0.27X and 0.92X, respectively; 0.36X and 0.96X, respectively; and 0.53X + 0.95X, respectively. Even spray nozzles with limited spray overlap of about one-eighth of the swath width were used to create equal-width IR and BR zones (about 50% of the corn row width, 76 cm). Early season rainfall occurred soon after herbicide application in both years (Figure 1). Weedy and weed-free checks were added. Treatments were arranged in a randomized complete-block design with six replications (Hoshmand 1994). Individual plots measured 3 by 10.7 m in 2003 and 3 by 13.7 m in 2004.

The dual-boom ZHA backpack sprayer consisted of a frame that held two adjacent tandem spray booms that

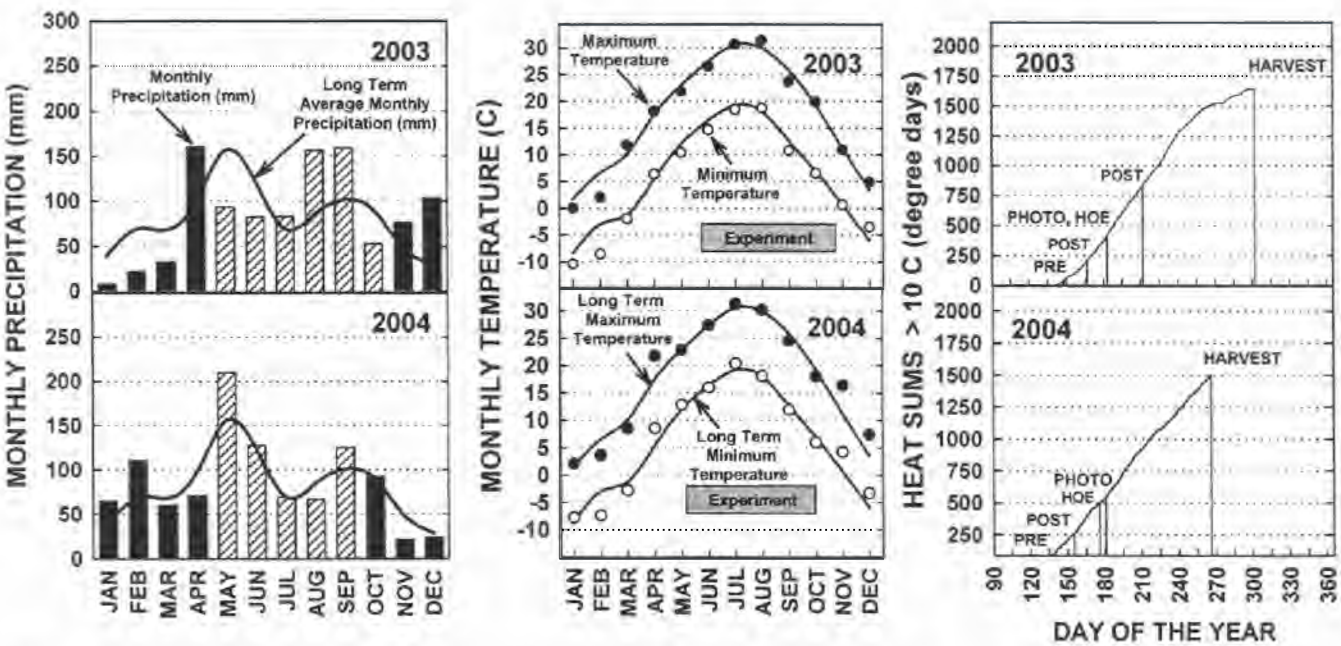

Figure 1. Monthly precipitation (bars) and the long-term (1996 to 2001) average monthly precipitation (lines) vs. month in 2003 and 2004 at the Greenley Research Center near Novelty, MO (left panels). Monthly average maximum (solid circles) and minimum (open circles) air temperatures and long-term (1996 to 2001) averages (lines) vs. month (middle panels). Cumulative heat sums after planting >10 C (i.e., growing degree C days) vs. day of the year (right panels). Hatched bars (left panels) or horizontal gray bars ("experiment" in middle panels) correspond to the duration of the experiment (Abbreviations: PHOTO, photographed in-row (IR) and between-row (BR) weed cover; HARVEST, "Weed-free" plots were either hoed (HOE) or sprayed with glufosinate [POST].)

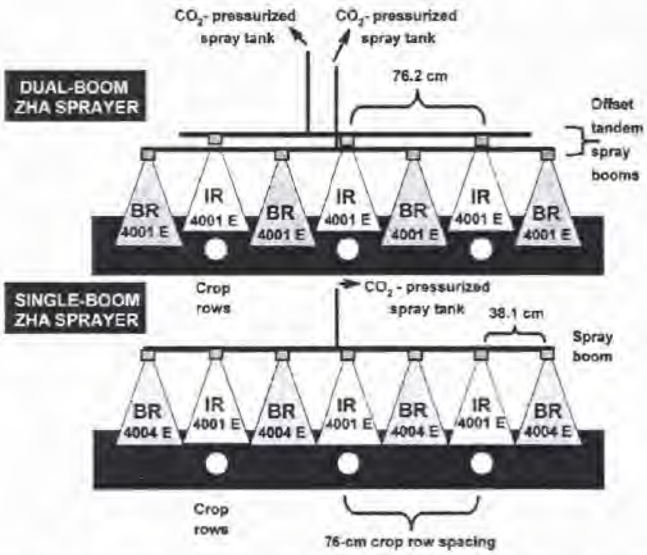

Figure 2. Spray boom configurations for dual-boom and single-boom zone herbicide application relative to crop rows; nozzle spray tips: even TeeJet® 4001E and 4004E with slight overlap (about one-eighth band width). (Abbreviations: IR, in-row; BR, between-row.)

Table 2. Parameters for dual- and single-boom zone herbicide application (ZHA) in 2003 and 2004.

	Nozzle spray tip[b]		Carrier volume	
ZHA method[a]	In-row	Between-row	2003	2004
			L/ha	
Single-boom	4001 even	4004 even	214	214
	4001 even	4003 even	193	196
	4001 even	4002 even	160	165
Dual-boom	4001 even	4001 even	142	143

[a] All backpack sprayer applications were pressurized with compressed CO_2 at 207 kPa and operated at a ground speed of 3.5 km/ha. Dual- and single-boom ZHA sprayers are illustrated in Figure 2.

[b] TeeJet®, Spraying Systems Co., P.O. Box 7900, Wheaton, IL 60189–7900.

were offset from one another (Figure 2). The single-boom ZHA backpack sprayer used different types of even-spray nozzles spaced 38.1 cm apart on one spray boom frame. Application parameters for each spray boom configuration are summarized in Table 2.

Calibration for dual-boom ZHA was the same as for band-applied herbicides. Calibration for single-boom ZHA depended on both spray tank herbicide concentration and fractional carrier volume output of IR and BR nozzles. The carrier volume output of various combinations of individual IR and BR nozzles on single booms was measured three times at the same pressure used for spraying. Then, the following measurements were tabulated: (1) the fraction of the total sprayed carrier volume that was distributed separately to IR and BR even nozzles, (2) the average fractional carrier volume sprayed per plot area (i.e., the average of measured fractional carrier volumes applied IR and BR), and (3) the ratio of measured fractional carrier volumes applied BR to that applied IR (Table 3). By choosing different combinations of various IR and BR even nozzle spray tips, which applied different carrier volumes, different ratios of IR and BR herbicide rates could be applied. Next, while keeping sprayer pressure and ground speed constant in the field, the total carrier volume output of the single-boom ZHA system was measured. Finally, enough herbicide was added to the spray tank so that the 1 X rate, or other desired maximum rate, was applied through the BR even nozzle spray tips for the treated area. Thus, IR and BR even nozzles were chosen to apply the desired fractional carrier volumes over and between rows to achieve the desired IR and BR herbicide rates. For the single-boom ZHA system, the achieved IR herbicide rates were slightly more than desired, whereas the achieved BR herbicide rates were slightly less than desired.

To maintain uniform IR and BR zone widths, spray boom height above the ground was maintained by suspending booms on a frame from guy lines that ran from each end of the frame to the top of the backpack frame holding the sprayer. The guy lines suspended the weight of the boom frame from the applicator's back, rather than the applicator's arms, minimizing applicator fatigue and variation in boom height during spraying. The boom heights above the ground for the single- and dual-boom ZHA sprayers were about 71 and 53 cm in 2003, respectively, and 64 and 51 cm in 2004, respectively. Boom heights were adjusted by visual inspection to ensure limited spray overlap between adjacent nozzles. The appearance of spray overlap differed between years because of variation in soil surface roughness, residue, and wind speed between years.

Measurements. After full emergence, corn plant density was measured by counting all corn plants in the two center rows of the four-row plots (Table 1). Corn was combine-harvested from the two center rows 9.1 m long in 2003 and 11.4 m long in 2004, and grain yields were adjusted to 15% moisture content.

Projected ground cover of all weeds (%) ("total weed cover" hereafter) was estimated from photographs' taken separately in and between crop rows to document the effect of the treatments on weeds, rather than predicting yield loss from weed cover (Table 1; Figure 1). Crop

[6] Olympus D-620 L digital camera in 2001 and Olympus C4040 zoom digital camera after 2002; Olympus America Inc., 2 Corporate Center Drive, Melville, NY 11747-3157.

Table 3. Operating parameters for single- and dual-boom zone herbicide application (ZHA) for several even spray nozzle spray tips.

Type of ZHA boom	Row position or "zone"[a]	Nozzle spray tip[b]	Desired herbicide rate: Desired fractional herbicide rate in IR or BR zones	Desired herbicide rate: Average ratio of fractional herbicide rates per sprayed plot area[c]	Desired herbicide rate: BR/IR ratio of desired fractional herbicide rates	Measured carrier volume for single-boom: Measured fractional carrier volume in IR or BR zones	Measured carrier volume for single-boom: Average ratio of fractional carrier volume per sprayed plot area[d]	Measured carrier volume for single-boom: BR/IR ratio of measured carrier volume
			fracton of 1× rate			fracton of total volume		
1 Single	IR	4001 E	0.25	0.63	4.00	0.27	0.60	3.69
	BR	4004 E	1.00			0.92		
2 Single	IR	4001 E	0.35	0.68	2.86	0.36	0.66	2.88
	BR	4003 E	1.00			0.96		
3 Single	IR	4001 E	0.50	0.75	2.00	0.53	0.74	1.90
	BR	4002 E	1.00			0.95		
4 Dual	IR	4001 E	0.25	0.63	4.00	—	—	—
	BR	4001 E	1.00			—	—	—
5 Dual	IR	4001 E	0.35	0.68	2.86	—	—	—
	BR	4001 E	1.00			—	—	—
6 Dual	IR	4001 E	0.50	0.75	2.00	—	—	—
	BR	4001 E	1.00			—	—	—

[a] Abbreviations: IR, in-row; BR, between-row; ZHA, zone herbicide application.
[b] TeeJet®, Spraying Systems Co., P.O. Box 7900, Wheaton, IL, IL 60189–7900.
[c] IR and BR zones are each 50% of the plot area. Average fractional rate per sprayed plot area = (IR fractional rate + BR fractional rate)/2.
[d] Average fractional volume per sprayed plot area = (IR fractional volume + BR fractional volume)/2.

cover was not measured. Before taking photographs, corn foliage overhanging and obscuring the IR and BR zones was pulled back with 1-m^2, wooden frame panels covered with black cloth. An orange-colored dowel was extended at a right angle, 19 cm out from the crop row at the soil surface toward the row middle to indicate the width of the IR zone in the photographs. IR and BR weed cover were separated from one another using black panels extended to the soil surface to prevent IR weed foliage from overhanging and obscuring BR weed cover, and vice versa. Four IR and four BR photographs were taken per plot vertically (i.e., camera facing toward the soil surface) with a digital camera,[6] at a height of 119 cm in four blocks each year. Each photograph cone-sponded 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. Image analysis software' was used to select IR and BR zones and automatically superimpose a 20- by 20-pixel grid over each cropped photograph. Weed cover (WC) of giant foxtail and broadleaf weeds in weedy checks was calculated using the following equation:

$$WC = (nIN) \times 100$$

where WC equals giant foxtail or broadleaf weed pro- ected cover (%); n equals the number of grid intersections in the grass or broadleaf weed cover categories; and N equals the total number of grid-line intersections per cropped photograph.

All photographs were taken on 1 d under the shade of an umbrella to minimize contrast between brightly lit and heavily shaded spots and to ensure uniform diffuse light intensity for photographs. This allowed total weed cover to be deteffnined using the software's automated measurement capacity to distinguish "green" from other colors. Total weed cover (%) of all plots was calculated as the ratio of green pixels to total pixels per photograph X 100. In both years, four IR photographs per plot were averaged for reporting IR weed cover, and four BR photographs per plot were averaged for reporting BR weed cover.

Statistical Analysis. All ANOVAs (Hoshmand 1994) were conducted on measured variables (i.e., corn yield and IR and BR total weed cover) using statistical software (SPSS 2003) both separately by year and for both years, and herbicide rates were expressed as fractions (i.e., fraction of a 1 X rate). When data were statistically

' Sigma Scan Pro version 5 software, SPSS Science, SPSS Inc., 233 South Wacker Drive, Chicago, IL 60606-6307.

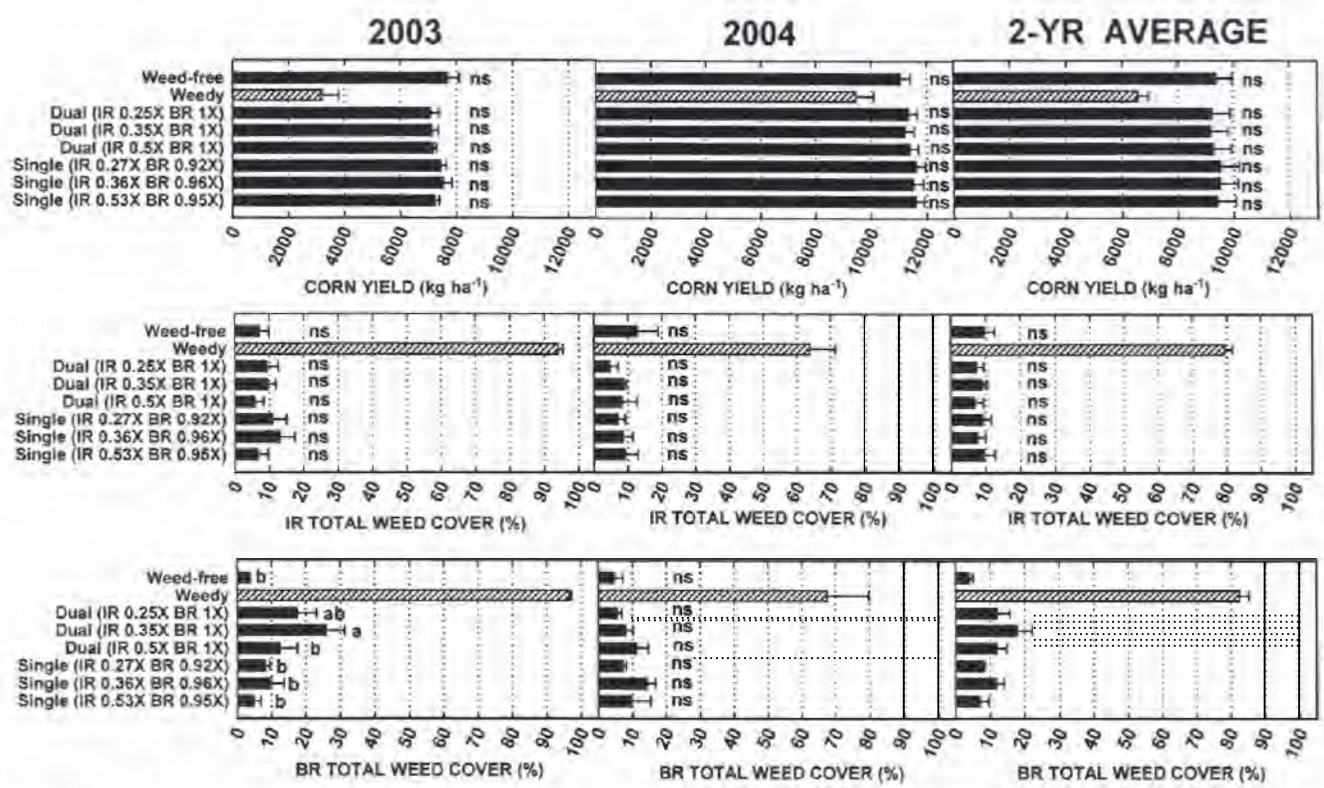

Figure 3. Corn grain yields, in-row (IR) total weed cover, and between-row (BR) total weed cover for single-boom and dual-boom zone herbicide application treatments in 2003 and 2004. Means ± standard errors are presented. For each variable within each year, means followed by no letter or the same letter were statistically indistinguishable by Fisher's protected LSD ($P < 0.05$), after excluding the weedy check from ANOVA. Abbreviation: NS, nonsignificant.

analyzed for both years, treatments and year were included as separate model terms.

The first null hypothesis was that corn grain yields of the weed-free checks were greater than the weedy checks and that IR and BR total weed cover of the weed-free checks were each less than the weedy checks. ANOVA was used to test these hypotheses (Hoshmand 1994). After these null hypotheses were verified to establish that weed populations and growth in the weedy checks were great enough to reduce yields compared with the weed-free checks, the weedy checks were excluded from subsequent statistical analyses to better distinguish differences between the weed-free check and the various treatments.

The second null hypothesis was that there were no differences in each of the three measured variables (corn grain yields, IR total weed cover, or BR total weed cover) between the weed-free checks and the treatments (i.e., ZHA with dual- or single-booms at three fractional herbicide rates). Data were subjected to ANOVA, and means were separated by Fisher's protected LSD test (P 0.05) (Hoshmand 1994).

RESULTS AND DISCUSSION

Corn Grain Yields. The corn grain yields in the weed-free check were 7,670 (±430) kg/ha [mean (±standard error), hereafter] in 2003 and 11,060 (±360) kg/ha in 2004, which were 67 and 104% of the yield goal for which the corn was fertilized in 2003 and 2004, respectively (i.e., 10,400 kg/ha). Growing conditions favored corn grain yields in 2004 (i.e., July to Sept. rainfall was average or above average) (Figure 1).

Corn grain yields of the weedy check were less than the weed-free checks in both years and for their 2-yr average and were reduced more in 2003 than in 2004 (Figure 3). Grain yields in the weedy checks were 3,190 (±600) kg/ha in 2003 and 9,450 (±670) kg/ha in 2004, which were 42 and 85% of that in the weed-free checks in 2003 and 2004, respectively.

Although corn grain yields are very sensitive to reduced stands (Hoeft et al. 2000), yield differences between years cannot be attributed to differences in corn plant density because corn stands were statistically indistinguishable for the weed-free and weedy checks.

When weed-free and weedy checks were averaged together, stand densities were 80,190 (±870) and 62,990 (± 860) seeds/ha in 2003 and 2004, respectively. Although corn stands were 106% of planting intentions in 2003, weed-free corn grain yields were reduced compared with the goal for which the corn was fertilized. In contrast, in 2004, weed-free grain yields achieved the expected yield goal for which corn was fertilized although stands were 82% of planting intentions, which was probably due to an earlier planting date (Table 1). Weather conditions, especially seasonal rainfall, apparently favored corn grain yields in 2004 compared with 2003 (Figure 1).

Corn grain yields for all dual- and single-boom ZHA treatments with preemergence herbicides were statistically indistinguishable from each other and from the weed-free check and they exceeded the weedy check (Figure 3). In separate statistical analyses by year and for both years, corn grain yields were independent of both the type of ZHA boom and the fractional herbicide rate.

In- and Between-Row Total Weed Ground Cover. Because responses for maximum BR weed canopy height (data not presented) and weed cover were similar, only IR and BR total weed cover will be presented (Figure 3). By midseason, IR and BR total weed cover of weedy checks were greater than that of the weed-free checks, as expected. IR and BR total weed cover in the weedy checks were also greater in 2003 than in 2004. In 2003, IR and BR total weed covers were 92.9 (± 1.2) and 94.3% (± 1.0), respectively, whereas in 2004, they were 71.5 (±5.8) and 73.6% (-1-6.4), respectively. Differences in total weed cover between years may be due to the combination of (1) different, but genetically related, corn varieties grown in each year; (2) an earlier planting date in 2004 than in 2003; and (3) weather that favored greater corn growth, interference, and grain yields in 2004.

Giant foxtail accounted for most IR and BR total weed cover in the weedy checks in both years. For the average of both the IR and BR zones in 2003, giant foxtail cover was 89.0% (± 1.9), and broadleaf weed cover was 4.6% (± 1.5), whereas in 2004, giant foxtail cover was 50.9% (±5.5), and broadleaf weed cover was 21.7% (± 4.1).

IR total weed cover was unaffected by the type of ZHA boom and herbicide rate compared with the weed-free check in both years (Figure 3). Because BR total weed cover responded to treatment differently between years (i.e., year and treatment interacted statistically for this measurement), LSD's for the 2-yr average are not presented, although results are graphed. In 2003, BR total weed cover of some treatments exceeded the weed-free check for some dual-boom ZHA treatments, but not for any single-boom ZHA treatment. In 2004, BR total weed cover was unaffected by all ZHA treatments compared with the weed-free check. Even when midseason BR total weed cover was as great as 25% (i.e., dual IR 0.35X BR 1X in Figure 3), corn grain yields were statistically indistinguishable from the weed-free check yields.

For single-boom ZHA in both years, IR and BR total weed cover were low (all ≤ 15%) (Figure 3). However, IR and BR PRE herbicide treatments differed in both herbicide rate and spray coverage, as estimated by spray carrier volume for the different even nozzle spray tips (Table 2). Thus, fractional herbicide rates and spray carrier volume interacted in single-boom ZHA. Nevertheless, PRE herbicides reduced IR and BR total weed cover equally well, independently of the tested range of herbicide rates or carrier volumes. Apparently at the reduced rates used, the PRE herbicides can vary greatly in spray coverage (i.e., carrier volumes with different nozzle types) without loss of weed control. We were unable to find refereed publications on the impact of spray coverage on weed control with PRE herbicides in corn or other crops.

In previous research, BR total weed cover was greater than IR total weed cover (Donald et al. 2004a, 2004b). This difference also was observed for some dual-boom ZHA treatments in 2003 (Figure 3). However, IR and BR total weed cover were statistically indistinguishable among treatments in 2004. Differences between experiments in between- and IR total weed cover may be due to differences in (1) crop management (e.g., different corn varieties planted at different times); (2) weather; and (3) the timing when weed cover was photographed each year. This latter reason is the most likely explanation for differences because total weed cover was photographed much later in the growing season in previous research (Donald et al. 2004a, 2004b) than in this experiment (Figure 1).

The research documents that all single-boom ZHA treatments were statistically indistinguishable from dual-boom ZHA or the weed-free check, based on corn grain yields and IR total weed cover in 2 yr, and BR total weed cover in 1 yr (Figure 3). Modifying a spray boom for single-boom ZHA is much less costly than using a dual-boom ZHA system because the latter requires two separate spray tank–hydraulic boom systems. Lower setup costs for the modified single-boom ZHA compared with

Table 4. Comparison of dual- and single-boom zone herbicide application (ZHA) with broadcast application.

General characteristic	Specific characteristics	Herbicide application system: Broadcast	Zone herbicide application: Single boom	Zone herbicide application: Dual boom
Sprayer features	Number of booms, sprayer systems, and spray tanks for herbicides	One	One	Two
	Type of spray nozzle tip	Flat fan	Even for banding	Even for banding
	Are IR and BR nozzle tips the same?	Yes	No	Yes
	Does the distance between IR and BR nozzle spray tips on the boom correspond to the row width?	Possibly yes, but not required	No, one-half of crop row width	Yes, banding zones over crop rows and zone between crop rows
	Do sprayed IR = BR zones correspond to about one-half of the row widths?	No, spray overlap	Yes	Yes
	Are IR nozzles centered IR, and BR nozzles centered BR?	Possibly yes, but not required	Yes	Yes
	Maximum boom height for crop clearance limiting application with most commercial nozzle spray tips	64 to 127 cm	64 cm for a 40° angle even nozzle spray tips to create a 46-cm-wide zone at the ground; boom height must be lowered for narrower zone widths with commercial nozzle spray tips	
	Spray overlap between adjacent nozzles across boom swath	one-half	1/16th to 1/8th	1/16th to 1/8th
	Are spray shrouds or shields needed to prevent spraying off target compared with rows in high wind?	No, weed control is not reduced by wind	Yes, desirable	Yes, desirable
Herbicide rate	Are IR and BR herbicide rates the same?	Yes, uniform across crop rows	BR rate > IR rate	BR rate > IR rate
	Can herbicide rate be varied continuously or in steps?	Continuously	Discrete steps for IR and BR positions because output of nozzles' spray tips for the IR and BR positions are discrete.	Continuously
	Is herbicide rate varied by changing IR and BR nozzle tips to change carrier volume sprayed?	No, herbicide concentration in spray tank is varied	Yes, but herbicide concentration in spray tank is also varied	No, but herbicide concentration in spray tank is varied
Spray volume	Is carrier volume output per nozzle and spray coverage equal across rows?	Yes	No, IR < BR	Yes, IR = BR
Misapplication	Can skips between sprayer passes cause loss of weed control?	Yes	Yes	Yes
	Are boom height and spray overlap between nozzles critical to prevent skips?	No, when there is 50% overlap of adjacent nozzle	Yes	Yes
	Is it desirable to control boom height by mounting booms on planters for preemergence herbicides?	No	Yes	Yes
	Does nozzle spray tip wear (output) need to be checked periodically and worn nozzle spray tips replaced in order to maintain proper calibration?	Yes	Yes, critical	Yes, critical

[a] Abbreviations: IR, in-row; BR, between row.

the dual-boom ZHA would help make reduced-rate ZHA more cost-effective and acceptable to farmers. The characteristics of dual- and single-boom ZHA systems were compared with broadcast herbicide application to summarize the advantages and disadvantages of both systems (Table 4).

Recently, representatives of the herbicide manufacturing industry voiced reservations about the consistency of weed control performance of conventional, reduced-rate broadcast-applied herbicide treatments from site to site (Doyle and Stypa 2004). As documented in Donald et al. (2004a, 2004b), reduced-rate ZHA is an alternative to broadcast-applied reduced-rate treatment and addresses those concerns for some PRE herbicides, chiefly crop yield and both weed control performance and consistency. However, farmers should check nozzle wear frequently to maintain proper calibration of single-boom ZHA. In addition, before ZHA will be accepted and adopted by farmers, it must be tested with other herbicide mixtures and in additional crops. It is unlikely that farmers will adopt ZHA if it has been proven to work for only one crop and one herbicide combination. It also is likely that this approach will favor farmer profitability at the expense of herbicide manufacturers and distributors because it reduces total herbicide use.

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