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Alternative Ways to Control Weeds Between Rows in Weeded Check Plots in Corn (*Zea mays*) and Soybean (*Glycine max*)[1]

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Abstract: Weeded check plots are an integral part of most weed control experiments. They provide a measure of the maximum crop yield without weed competition in a given site-year environment. The traditional way to create weeded check plots is to hoe and pull weeds by hand in the row and hoe weeds between rows. But erratic heavy rainfall can prevent timely hoeing. The objective of this experiment was to compare faster, less-laborious mechanized ways to control weeds between crop rows as alternatives to hoeing in corn and soybean. Hoeing, the traditional method for controlling weeds between crop rows, was compared with either repeated mowing using a cord-mower or a string-trimmer or shallow tilling with a rototiller between rows. Weeds growing in rows were controlled by hand-pulling and hoeing because the focus of the experiment was on speeding weed control between rows. All four methods for controlling weeds between crop rows were equally effective when measured as either corn or soybean yield, visual rating of weed control, or weed ground cover in two years under contrasting rainfall patterns. Cord-mowing or string-trimming between rows was possible when soil was dry enough to walk upon but too wet to hoe or rototill.

Nomenclature: Corn, *Zea mays* L. 'Pioneer 3379'; soybean, *Glycine max* (L.) Merr. 'Pioneer 9381'.
Additional index words: Mowing, rototilling, sustainable agriculture, tillage, SETFA.
Abbreviations: BR, between row; IR, in row.

INTRODUCTION

Weeded or "weed-free" check plots are an integral part of most weed management experiments. They estimate the maximum potential yield without weed competition for a given site-year environment. Of course, weed-free yield varies from site to site and year to year in response to other factors such as changing weather or crop management. In weeded check plots, weed control must start before weeds reduce crop yield and must be repeated in a timely fashion until late-emerging weeds no longer reduce yield (Oliver 1988; Radosevich et al. 1997; Zimdahl 1980). Complete season-long weed control (i.e., bare ground) is not necessary to achieve maximum yield because late-emerging weeds do not reduce yield after a critical period (Cardina et al. 1995; Knake and Slife 1965; Oliver 1988; Radosevich et al. 1997). This critical period is defined by experiments varying time of weed removal after crop emergence. Such experiments demonstrate that weed control does not need to be absolutely complete until harvest to achieve maximum yield. But timely weed removal is essential.

The traditional way to create weeded check plots is to hoe weeds between crop rows (BR) and to hoe and pull weeds in rows (IR). But erratic, heavy rains can prevent timely hoeing and hand-pulling. Quicker ways are needed to manage weeds between rows in corn and soybean. The goal is to prevent any crop yield loss caused by weed competition, which may not necessarily require complete removal of all weeds until harvest.

Cord-mowing (i.e., Dr. Trimmer mower), string-trimming (i.e., "weed wacking"), and rototilling have potential for mechanically controlling weeds between rows. The research objective was to compare the crop yield and weed control efficacy of these faster, less labor-intensive, mechanized ways to control weeds between crop rows with hoeing, the traditional method, in corn and soybean. IR weed control was not the focus of the experiment. IR weeds were controlled by hoeing and hand-pulling.

MATERIALS AND METHODS

Treatments. The treatments were an untreated weedy check and four BR weeding methods: shallow BR hand-hoeing (i.e., cutting weed shoots off at or slightly below

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Table 1. Dates of field operations, treatments, and measurements.

	Corn		Soybean	
Field operation, treatment, or measurement	1994	1995	1994	1995
Field operations				
Fallow or crop in previous year	Fallow	Soybean	Fallow	Corn
Moldboard plow for primary tillage and site preparation	3/18	—	3/18	—
Disc plow for primary tillage	4/4	—		4/4
Soil insecticide applied	5/5	—	5/5	—
Fertilize plots with broadcast N (corn only), P and K	5/11	6/14	5/5	6/14
Field cultivate to incorporate fertilizer and prepare seed bed	5/18	6/15	5/18	6/15
Plant crop	5/19	6/19	5/19	6/19
Initial crop emergence	5/25	6/26	5/25	6/26
Treatments				
Hoe between rows and/or hoe/hand pull in rows	6/20	7/5–7	6/20–21	7/11–12
	7/12–13	7/19	7/12–13	7/24–25
	—	8/14		
String-trim between rows and hoe/hand pull in rows	6/16–17	7/7	6/16–17	7/11–12
	7/12	7/19	7/12	7/24–25
	—	8/14	—	—
Cord-mow and hoe/hand pull in rows	6/16–17	7/5–7	6/16–17	7/11–12
	7/12	7/19	7/12	7/24–25
	—	8/14	—	—
Roto-till between rows and hoe/hand pull in rows	6/16	7/5	6/16	7/11–12
	7/12	7/19	7/12–13	7/24–25
	—	8/14	—	—
Measurements				
Determine crop stand	6/8	6/30	6/10	6/30
Take video photographs of weed ground cover	8/9	8/16	8/10–11	8/18
Visually rate weed control	8/8	8/18	8/8	8/18
	10/5	10/5	10/5	10/5
Harvest	10/21	11/7	10/20	10/23

the soil surface), shallow BR rototilling,[3,4] BR cord-mowing[5] about 2.5 cm above the soil surface, and BR mowing with a hand-held string-trimmer[6] close to the soil surface (Table 1). The crop row, BR, and IR widths were 76 cm, about 62 cm, and about 14 cm, respectively. IR weeds were hoed and pulled for all four BR treatments. Weed control was started as early as weather allowed and was repeated 2 to 3 times throughout the growing season (Table 1).

Four-row plots measured 3 by 9.1 m. A randomized complete block design with four and five blocks was used in 1994 and 1995, respectively (Sokal and Rohlf 1981). Blocking was based on weed cover observed in previous years on the site.

Common Agronomic Practices. Experiments were conducted on adjacent sites in a corn–soybean rotation in 1994 and 1995 at the Bradford Experimental Farm in central Missouri near Columbia (38°, 53 min, 43.5 sec N, 92°, 12 min, 37.9 sec W, 883 m altitude). The soil was a Mexico silty clay loam (fine, smectitic, mesic Aeric Vertic Epiqualfs) with 18 to 20% sand, 46 to 48% silt, 34% clay, 2.9 to 3.4% organic matter, a cation exchange capacity of 13.5 meg/100 g, and a pH of 5.5 to 5.7. Field operation dates for treatments and measurements are summarized for each crop each year (Table 1). Weather data were collected at the Bradford Experimental Farm in 1994, but data from the nearby Sanborn Experimental Field in Columbia were substituted in 1995 because the automated weather equipment failed at the Bradford Farm (Figure 1). The site was chisel-plowed in spring and field-cultivated for seedbed preparation and winter annual weed control.

In the weedy treatment, giant foxtail (*Setaria faberi* Herrm. #[7] SETFA), the major grass weed present, accounted for 76 and 90% of midseason total weed ground cover in corn in 1994 and 1995, respectively. It was 65 and 54% of total weed cover in soybean in 1994 and 1995, respectively. Common ragweed (*Ambrosia artemisiifolia* L. # AMBEL) and waterhemp spp. (*Amaranthus*

[3] Troy-Bilt Mini-Tiller Model 12001, Troy-Bilt Manufacturing Co., 102nd Street and 9th Avenue, Troy, NY 12180.

[4] Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, 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.

[5] Dr. Trimmer mower, 5.0 HP 2-cycle, XL Pro Country Home Products, Ferry Road, Box 89, Charlotte, VT 05445.

[6] Gasoline Trimmer/Cutter Model 350 G, John Deere Co., 1400 3rd Avenue, Moline, IL 61265.

[7] 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.

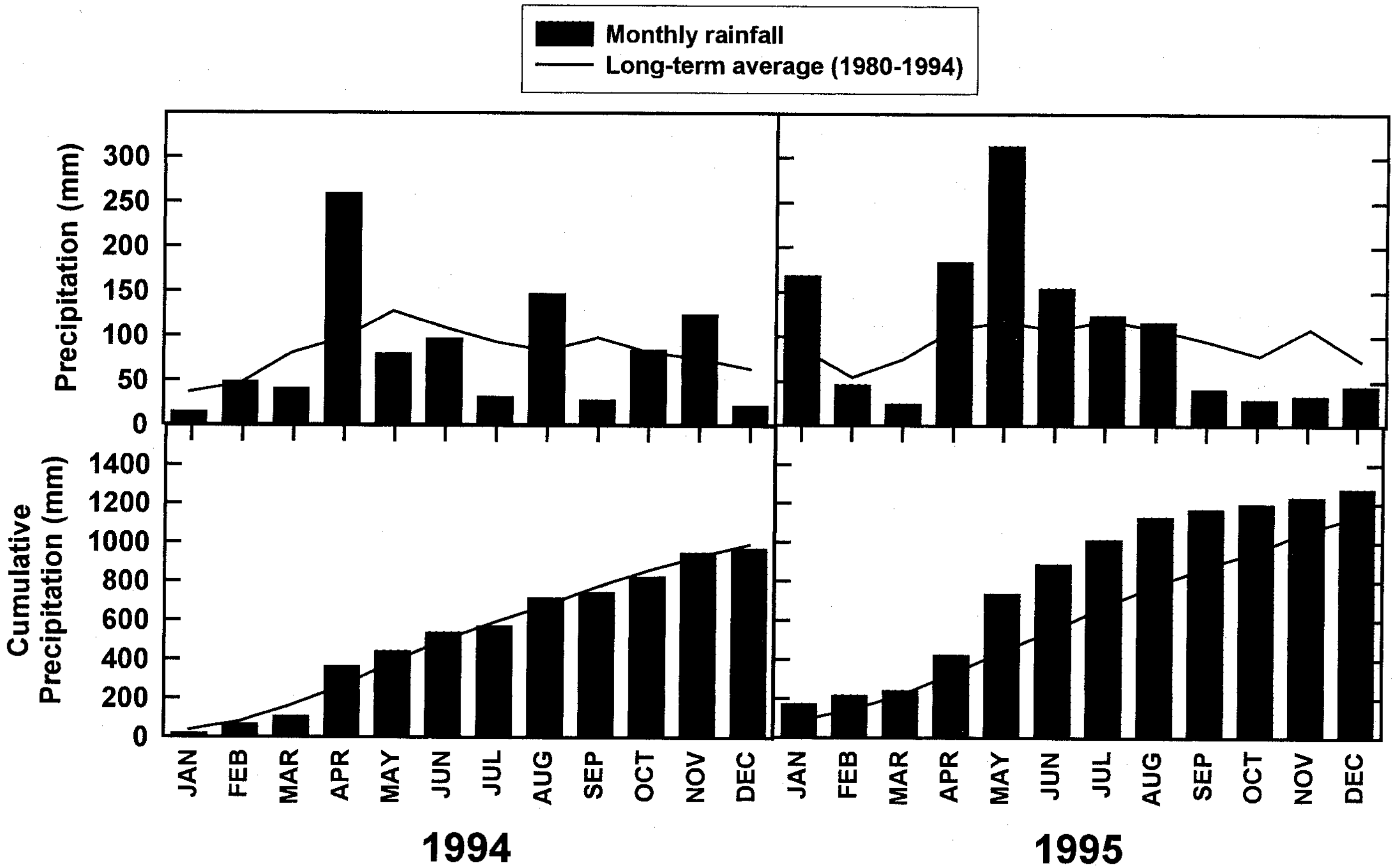

Figure 1. Monthly precipitation and cumulative monthly precipitation (bars) in 1994 and 1995 compared with long-term averages (1980 to 1994) (solid lines) at the Bradford Experimental Farm and Sanborn Field, respectively.

spp.) were the major annual broadleaf weeds. The following weeds were also present, but sparse: common lambsquarters (*Chenopodium album* L. # CHEAL), giant ragweed (*Ambrosia trifida* L. # AMBTR), hemp dogbane (*Apocynum cannabinum* L. # APCCA), horsenettle (*Solanum carolinense* L. # SOLCA), ivyleaf morningglory [*Ipomoea hederacea* (L.) Jacq. # IPOHE], ladysthumb (*Polygonum persicaria* L. # POLPE), Pennsylvania smartweed (*Polygonum pensylvanicum* L. # POLPY), tall morningglory [*Ipomoea purpurea* (L.) Roth # PHBPU], velvetleaf (*Abutilon theophrasti* Medik. # ABUTH), and yellow nutsedge (*Cyperus esculentus* L. # CYPES).

Corn Production Practices. Corn was fertilized with nitrogen, phosphorous, and potassium for a yield goal of 7,520 kg/ha each year based on soil tests and University of Missouri Extension recommendations. Fertilizers were broadcast before planting and were incorporated by field cultivation for seedbed preparation. NH_4NO_3-N-P_2O_5-K_20 was applied at 140-20-20 kg/ha in 1994 and at 140-0-0 kg/ha in 1995, respectively.

'Pioneer 3379' corn seed was planted about 1.5 cm deep in 76-cm rows at 74,000 to 78,000 seeds/ha[8] (Table 1). Rainfall delayed planting in 1995 by one month compared with 1994 (Figure 1). Corn emerged about 6 to 7 d after planting. Corn was sprayed with chlorpyrifos [*O*-diethyl-*O*-(3,5,6-trichloro-2-pyridinyl)phosphorothioate] for cutworm (*Euxoa* spp.) control in 1994 based on University of Missouri integrated pest management guidelines.

Soybean Production Practices. Soybean was fertilized with phosphorous and potassium for a yield goal of 2,690 kg/ha in 1994 and 3,025 kg/ha in 1995 based on soil tests and University of Missouri Extension recommendations. NH_4NO_3-N-P_2O_5-K_20 was applied at 0-62-56 kg/ha in 1994 and at 0-56-50 kg/ha in 1995, respectively. Fertilizer application and incorporation were described earlier. 'Pioneer 9381' soybean seeds were planted about 1.5 cm deep in 76-cm rows at 420,200 seeds/ha[9] (Table 1).

[8] Four-row Maximerg corn planter, John Deere and Co., John Deere Road, Moline, IL 61265.

[9] Four-row 71 Flexi-Planter, John Deere and Co., John Deere Road, Moline, IL 61265.

Measurements. Weed control was evaluated visually at midseason and near harvest based on a scale of 0 (no control) to 100% (complete kill), and photographs were taken at midseason for measuring percentage of BR weed ground cover (Table 1). Because nearly closed corn and soybean canopies covered the soil surface when photographs were taken, BR photographs were taken after parting and pulling back the crop foliage with panels (1 by 1 m) to expose the BR soil surface and weed ground cover. Photographs were taken with video cameras[10] from 164 cm above the soil surface 76 and 51 d after emergence in 1994 and 1995, respectively, as weather allowed (Figure 1). Photographs corresponded to 1.5 and 1.1 m^2 of the soil surface in 1994 and 1995, respectively, using a 30- by 30-cm orange metal plate placed on the soil surface for calibration. Photographs were digitized[11] and saved as TARGA files for image analysis.[12] Ground cover of giant foxtail and broadleaf weeds was traced manually and pixels were expressed as a percent of total pixels per photograph. Percent giant foxtail and broadleaf weed ground cover were measured separately and summed for measurement of total weed ground cover. Averages of four separate photographs per plot are presented.

Corn seeds were combine-harvested from the two center rows in a 1.5- by 8.4-m area and gross yields were reported, adjusted to 15% moisture (Table 1). Soybean seeds were harvested similarly with a small plot combine, cleaned, and net yields adjusted to 13% moisture for presentation (Table 1).

Statistical Analysis. Data were subjected to ANOVA using statistical software (Sokal and Rohlf 1981; SPSS 1998). Means were separated by Duncan's Multiple Range test ($P \leq 0.05$).

RESULTS AND DISCUSSION

Corn Yield. Yield data were averaged across years because treatment-by-year interactions were not significant, although main effects due to treatment and year were each significant (Figure 2). Two-year average corn yields were not significantly different for all four IR-hoed + BR weed control methods (Figure 2). The yield of the weedy check was much lower than any of these four treatments. Corn yields averaged 2,670 kg/ha and 2,850

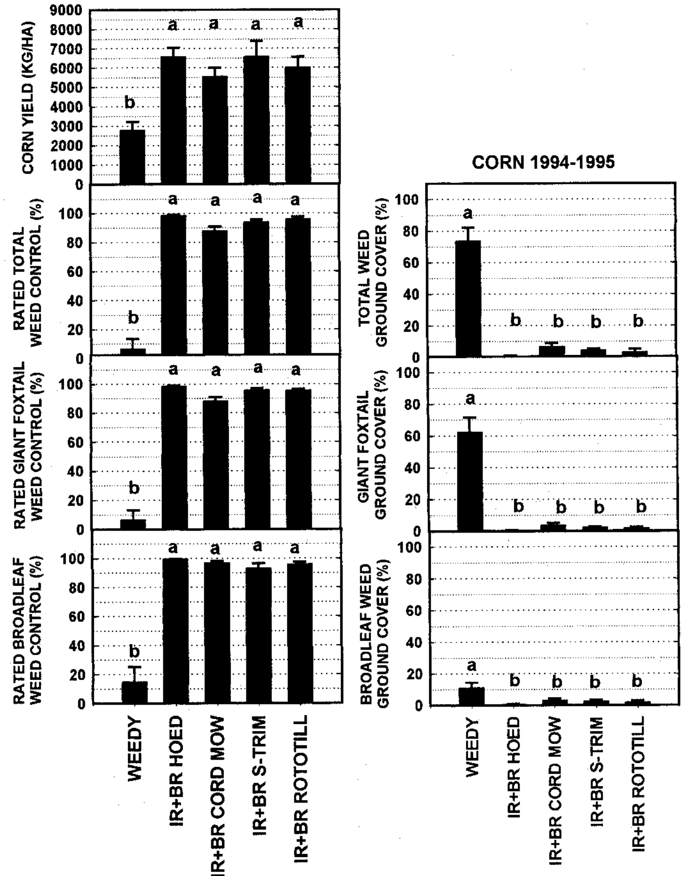

Figure 2. The effect of various in-row (IR) ± between-row (BR) weed control treatments on corn yield, midseason visual rating of weed control, and midseason weed ground cover between crop rows for 1994 and 1995. Means (bars) and standard errors (whiskers) are presented. Means followed by the same letter were not different by Duncan's Multiple Range test ($P \leq 0.05$). Abbreviation: S-TRIM = string trim.

kg/ha in the weedy treatment in 1994 and 1995, respectively. Weedy yields were 47 and 39% of the IR + BR-hoed treatment in 1994 and 1995, respectively. The IR + BR-hoed treatment is the standard weed-free treatment used to assess yield potential without weed competition in a given site-year environment. It achieved 76 and 97% of the yield goal for which the corn was fertilized in 1994 and 1995, respectively. Rainfall was below normal from May to July 1994, but was above normal for the same period in 1995 (Figure 1). Below-normal midsummer rainfall during corn silking and early seed filling probably limited the maximum weed-free yield potential at the site in 1994.

Weed Ground Cover and Visual Rating of Weed Control in Corn. The total BR weed ground cover was not significantly different among all four IR + BR treatments, but was much less than for the weedy treatment (Figure 2). IR treatments + either BR cord-mowing, BR

[10] XAPSHOT and RC-570 still video cameras, Cannon U.S.A., Inc., Still Video Systems Division, 1 Canon Plaza, Lake Success, NY 11024.

[11] SV-PC Digitizer Still Video Board, Cannon U.S.A. Inc., Still Video Systems Division, 3 Dakota Drive, Lake Success, NY 11024.

[12] SigmaScan and SigmaScan Pro. Version 1. Image analysis software (1995), Jandel Scientific, Inc. P.O. Box 7005, San Rafael, CA 94912-7005.

string-trimming, or BR rototilling are suitable alternatives to IR treatment + BR hoeing for controlling weeds, based on yield, visual rating of weed control, and BR total weed cover. Visual rating of weed control and weed ground cover data were combined over years because treatment-by-year interactions were not significantly different. Conclusions based on visual rating of weed control were similar to those based on BR weed ground cover and verified conclusions based on corn yield. But percent weed ground cover is superior to visual rating of control as a scientific measurement for the reasons summarized by Donald (1998). Because weed ground cover data were based on an objective measurement scale, data can be compared between years. Total and giant foxtail BR weed ground cover for the data set were negatively correlated with corn yield (Pearson correlation coefficient of −0.75 and –0.71 in 1994 and −0.61 and −0.62 in 1995, respectively, at P = 0.001).

The first BR mowing with a cord mower or string-trimmer killed emerged annual broadleaf weeds whose shoot apices were above the cutting height (personal observation). The first mowing killed some giant foxtail plants and suppressed and delayed subsequent giant foxtail growth by defoliation. But its foliage regrew from main and tiller bud meristems at or below the soil surface that were below the cutting height. A second or third mowing killed subsequent flushes of annual broadleaf weeds and giant foxtail. By the second or third mowing, crop canopy closure was nearly complete and crop shading suppressed subsequent summer annual weed emergence and growth. Sparse stands of yellow nutsedge were greatly suppressed but not killed by three mowings and crop shading.

In corn, the total BR weed ground cover in the weedy treatment was greater in 1995 (i.e., 81%) than in 1994 (i.e., 64%), probably because above-normal rainfall from May to July favored greater weed growth in 1995 than in 1994 (Figure 1). Favorable growing season temperatures, nitrogen fertilization, and adequate moisture probably favored rapid giant foxtail emergence and ground cover development.

Giant foxtail, annual broadleaf weeds, and yellow nutsedge were first removed before they could reduce yield (i.e., 3 to 3.5 wk and 1.5 to 2 wk after corn emergence in 1994 and 1995, respectively) (Table 1). Most weed species first reduce yield if not mechanically removed by 4 to 6 wk after corn emergence, but the critical period can range from 2 to 8 wk (Zimdahl 1980). For example, when wild-proso millet (*Panicum miliaceum* L.) was removed from irrigated corn 2 to 3 wk after crop emer-

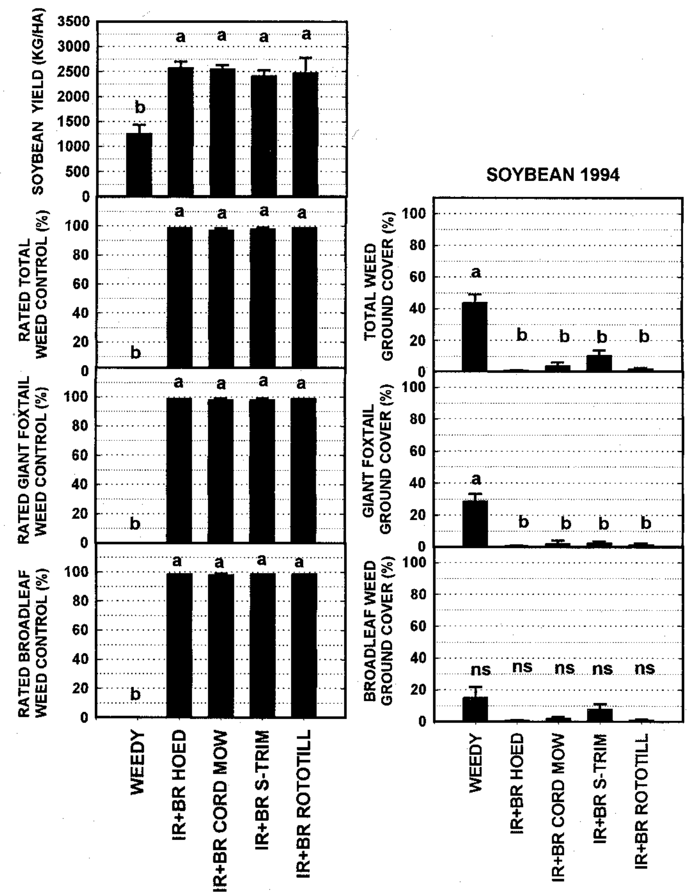

Figure 3. The effect of various in-row (IR) ± between-row (BR) weed control treatments on soybean yield, midseason visual rating of weed control, and midseason weed ground cover between crop rows in 1994. Means (bars) and standard errors (whiskers) are presented. Means followed by the same letter were not different by Duncan's Multiple Range test (P ≤ 0.05). Abbreviations: S-TRIM = string trim.

gence, yield was not reduced in Colorado and Nebraska (Wilson and Westra 1991). Yield was first decreased when removal was delayed until 4 wk after emergence. Green foxtail [*Setaria viridis* (L.) Beauv.] reduced nonirrigated corn yield only when removal was delayed until 5 wk after crop emergence in Canada (Sibuga and Bandeen 1980). In Illinois in nonirrigated corn grown in 100-cm-wide rows, yield was reduced 1, 2, 4, 6, and 16% when IR giant foxtail removal was delayed until it was 7.6, 15.2, 22.9, and 30 cm tall or at harvest (Knake and Slife 1969). However, elapsed time between corn emergence and giant foxtail removal was not reported.

Soybean Yield. Soybean yields are presented separately by year for clarity and comparison with the other variables, although the treatment-by-year interaction for yield was not significant (Figures 3 and 4). All other measured variables had significant treatment-by-year interactions. The soybean yields of the IR treatment +

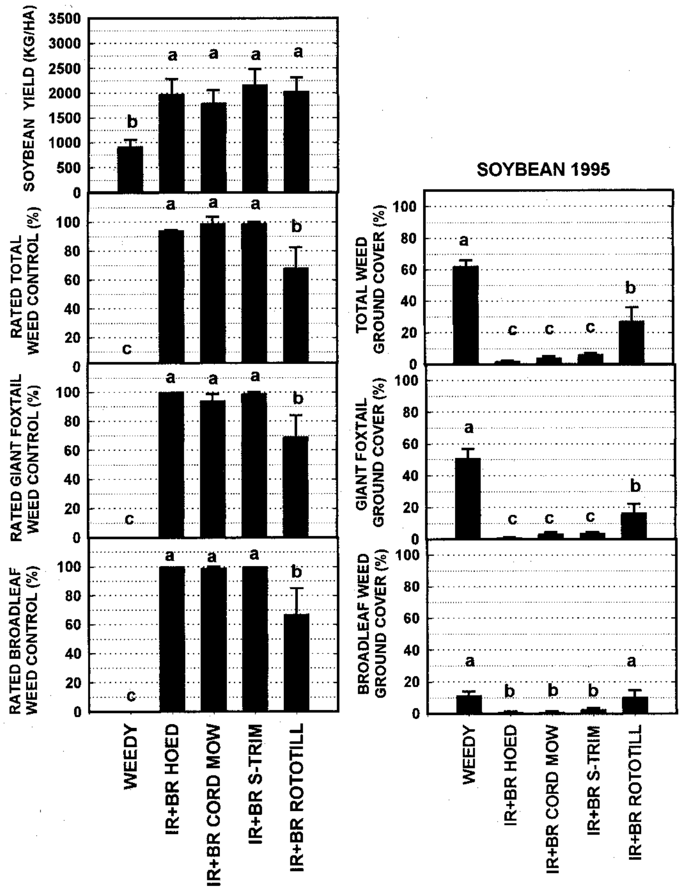

Figure 4. The effect of various in-row (IR) ± between-row (BR) weed control treatments on soybean yield, midseason visual rating of weed control, and midseason weed ground cover between crop rows in 1995. Means (bars) and standard errors (whiskers) are presented. Means followed by the same letter were not different by Duncan's Multiple Range test ($P \leq 0.05$). Abbreviations: S-TRIM = string trim.

either BR cord-mowing, BR string-trimming, or BR rototilling were not significantly different from each other or the IR + BR hoeing treatment, as observed for corn yield (Figure 2).

The soybean yield of all four IR + BR treatments was much greater than the weedy check (Figures 3 and 4). The yield of the weedy treatment averaged 1,260 kg/ha in 1994 and 920 kg/ha in 1995, which was 48 and 47% of the yield for the IR + BR hoed treatment in 1994 and 1995, respectively. The IR + BR hoed treatment, the standard to create weed-free plots, achieved 96 and 65% of the yield goal for which the soybean crops were fertilized in 1994 and 1995, respectively.

Weed Ground Cover and Visual Rating of Control in Soybean. Visual rating of weed control and weed ground cover data are reported by year because the treatment-by-year interaction was significant (Figures 3 and 4). Based on total, giant foxtail, and broadleaf BR weed cover, the four IR + BR treatments were not statistically different, and all were much less than the weedy check except for the IR + BR rototilled treatment in 1995 (Figures 3 and 4). In 1995, the soybean plots were rototilled only once because of mechanical failure. Nevertheless, in 1995 soybean yields for the four IR + BR treatments were not statistically different, although total, giant foxtail, and broadleaf BR weed ground cover was greater for the IR + BR rototilled treatment than for the IR hoed/hand-pulled + either BR hoed, BR cord-mowed, or BR string-trimmed treatments. Total and giant foxtail BR weed ground covers were negatively correlated with soybean yield (Pearson correlation coefficient of −0.91 and −0.92 in 1994 and −0.52 and −0.57 in 1995, respectively, at $P = 0.01$).

Total BR weed ground cover in the weedy soybean treatment was greater in 1995 (62%) than in 1994 (44%) (Figures 3 and 4), as observed for corn. Rainfall probably favored BR weed growth more in 1995 than in 1994 in both crops (Figure 1). However, total BR weed ground cover was greater in corn than in soybean in both years (64 versus 44% in 1994, respectively, and 81 versus 62% in 1995, respectively). Most BR total weed ground cover was giant foxtail in the weedy treatment in corn (76 and 90% of total ground cover in 1994 and 1995, respectively) and in soybean (65 and 54% of total ground cover in 1994 and 1995, respectively). A later planting date and greater rainfall in 1995 than in 1994 may have favored more BR broadleaf weed growth in soybean in 1995. Nitrogen fertilizer, applied only to corn, probably encouraged greater giant foxtail growth and cover development in corn than in soybean, as observed for foxtails and other weeds (Black and Siddoway 1977; Campbell et al. 1998; Hume 1982; Moyer and Dryden 1977; Sardi 1996; Schimpf and Palmbald 1980).

Giant foxtail and other emerged broadleaf weeds or yellow nutsedge were first treated 3 to 3.5 wk and about 2 wk after soybean emergence in 1994 and 1995, respectively. Reviews of the literature (Stoller et al. 1987) show that the treatments were started early enough to prevent yield loss in this study. For example, in a Maryland study, an annual grass mixture of giant green foxtail [*Setaria viridis* var. *major* (Gaudin) Pospichel] and fall panicum (*Panicum dichotomiflorum* Michx.) did not begin to reduce soybean yield until removal was delayed 8 wk after emergence in 2 of 3 years (Harris and Ritter 1987). In fact, only full season competition by this mixture reduced yield in a drought year. Wild oat (*Avena fatua* L.) did not reduce soybean yield even when weed removal was delayed until 4 wk after crop emergence in

Table 2. Qualitative comparison of alternative weed control methods.

Criteria	Between-row weed control methods					
	Herbicide	Hoeing and hand-pulling	Field cultivator	Cord-mower	String-mower	Rototiller
Equipment costs						
Equipment cost ($)	high (> $1,000)	very low ($25–50)	high (> $1,000)	medium ($500–900)	low ($100–200)	medium ($350–500)
Equipment durability	good	excellent	good	good	good	poor
Disposable materials and supplies	yes	no	no	yes	yes	no
Fuel	yes	no	yes	yes	yes	yes
Labor required per plot						
Labor cost per plot	low	very high	low	low	low	low
Training requirements	high	low	medium	low	low	low
Certification requirements	yes	no	no	no	no	no
Driver's license requirements	yes	no	yes	no	no	no
Timeliness						
Speed per research plot (not including setup)	very fast (< 1 min.)	very slow (15–30 min.)	very fast (< 1 min.)	fast (4.8 min.)	fast (3.2 min.)	slow (10 min.)
Soil must be dry for best weed kill	no	yes	yes	no	no	yes
Wind speed limits timeliness	yes	no	no	no	no	no
Simplicity	no	yes	yes	yes	yes	yes
Crop damage						
Type of damage	herbicide-dependent	shoot and root cutting	root cutting	shoot cutting	shoot cutting	root cutting
Resistant varieties prevent damage	herbicide-dependent	no	no	no	no	no
Treatable crop growth stages and duration of treatment without damage	herbicide-dependent	long	short	long	long	long
Can be used in-row, as well as between rows	yes	yes	no	no	no	no
Damage depends on crop row width	no	no	yes	yes	yes	yes
Crop shields minimize damage	yes	no	yes	no	no	no
Overall likelihood of crop damage	herbicide-dependent	low	stage dependent	low	low	low
Weed kill						
Efficacy (weed kill completeness)	herbicide- and weed-dependent	high	weed-dependent	weed-dependent	weed-dependent	weed-dependent
Weed kill	delayed	immediate	immediate	immediate	immediate	immediate
Kills small emerged annual weeds	yes	yes	yes	no	no	yes
Retreatment needed for flushes of later-emerging weed	herbicide-dependent	yes	yes	yes	yes	yes
Stimulates emergence of some weeds	no	yes	yes	no	no	yes
Maximum % plot area treatable in row crops	100%	100%	~60%	~70%	~70%	~60%
Adapted for different tillage system						
Disturbs soil surface	no	yes	yes	no	no	yes
Leaves soil surface cloddy	no	no	yes	no	no	yes
Disturbs or reduces surface residue	no	yes	yes	yes	yes	yes
Adapted for no-till farming systems	yes	no	no	yes	yes	no
Health or safety concerns						
Dermal and vapor exposure to chemicals	Herbicides and fuel	no	fuel	fuel	fuel	fuel
Protective clothing required	yes	no	no	yes	yes	yes
Protective eye wear required	yes	no	no	yes	yes	no
Hearing protection suggested	yes	no	yes	yes	yes	yes

North Dakota (Rathman and Miller 1981). Soybean yields were first reduced when shattercane [*Sorghum bicolor* (L.) Moench] was not removed until 6 wk after soybean emergence in two of three years in which soybean planting was in mid- to late May in Nebraska (Fellows and Roeth 1992). But in one year in which planting was delayed until mid-June, shattercane first reduced yield when not removed before 2 wk after crop emergence. Johnsongrass [*Sorghum halepense* (L.) Pers.], a perennial, competing with soybean for 4 wk after crop emergence did not reduce yield in Tennessee (Williams and Hayes 1984). But if it was not removed until 6 wk or later after crop emergence, yield began to be reduced. In nonirrigated soybean grown in 100-cm wide rows in

Illinois, yield was reduced 0, 0, 3, 7, and 60% when giant foxtail removal was delayed until it was 7.6, 15.2, 22.9, and 30 cm tall or at harvest (Knake and Slife 1969). The elapsed time between soybean emergence and giant foxtail removal was not reported.

Comparison of Methods of Creating Weeded Treatments. Qualitative criteria are tabulated for comparing various BR weed control treatments (Table 2). Each method has advantages and disadvantages for different situations. The potential advantages of the cord-mower and string-trimmer were relatively low labor cost and physical labor, speed of mowing, speed of weed kill, timeliness, low potential for crop damage, simplicity, adaptation to moist soil conditions, and potential adaptation to no-till farming systems. For cord-mowing or string-trimming, the soil needs to be only dry enough for walking, but must be much drier than this for effective hoeing, hand-pulling or rototilling. Consequently, as the soil dries after rainfall, weeds can be killed earlier by mowing than they can be killed by hoeing, hand-pulling, or rototilling. The time and labor cost per plot were ranked: hoeing > rototilling > cord-mowing = string-trimming. In addition, up to 70% of the plot area can be mowed. The limitations for rototilling were that it must be delayed until the soil is dry enough to work, it can damage crop roots, and it is limited to relatively wide row spacing.

Some weed scientists suggest that glyphosate [*N*-(phosphonomethyl)glycine]-resistant crops may reduce the labor and cost of creating weed-free checks. But not all crops or crop varieties are resistant to glyphosate. Moreover, time-of-weed-removal experiments comparing the use of mechanical weed removal with herbicides to define the critical period of weed competition show that the two methods are not comparable. Differences between mechanical weed removal and herbicides were demonstrated for volunteer corn removal from soybean with glyphosate and fluazifop {(±)-2-[4-[[5-(trifluoromethyl)-2-pyridinyl]oxy]phenoxy]propanoic acid} (Beckett and Stoller 1988), wild-proso millet removal from corn with cyanazine {2-[[4-chloro-6-(ethylamino)-1,3,5-triazin-2-yl]amino]-2-methylpropanenitrile} + tridiphane [2-(3,5-dichlorophenyl)-2-(2,2,2-trichloroethyl)oxirane] (Wilson and Westra 1991), johnsongrass removal from soybean with sethoxydim {2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one} (Williams and Hayes 1984), and common lambsquarters (*Chenopodium album* L.) removal from soybean with bentazon [3-(1-methylethyl)-(1*H*)-2,1,3-benzothiadiazin-4(3*H*)-one 2,2-dioxide] + acifluorfen {5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoic acid} + crop oil concentrate (Crook and Renner 1990). These time-of-removal experiments show that herbicides must be applied 1 to 2 wk before mechanical weeding to prevent comparable yield loss from weeds. Herbicide-treated weeds continued to compete with crops for a limited period after treatment before they eventually died. In contrast, mechanical methods kill most weeds and stop weed competition when treated. While mechanical methods such as hand-hoeing are equally effective for killing weeds at most treatment times, many herbicides become progressively less effective for killing weeds as weeds grow larger. In the past, herbicides were not used to create weeded check plots because they sometimes damaged crops and reduced yield, negating the goal of obtaining a maximum yield free from weed competition.

All four mechanical methods for controlling BR weeds (+ IR hoeing/hand-pulling) were equally effective when measured as either corn or soybean yield, visual rating of weed control, or BR weed ground cover in two years under different rainfall patterns (Figures 2 through 4). Although not used commercially at present, scaled-up BR cord-mowing or string-trimming between rows plus band herbicide over rows may have site-specific potential as an alternative weed management method to either field cultivation or broadcast herbicides for controlling weeds. This alternative has promise in environmentally sensitive areas for reducing soil erosion or water contamination by either sediment or herbicides. BR mowing or string-trimming may also have use in small-acreage, high-value horticultural crops or gardens. BR cord-mowing or string-trimming may speed BR weed control on small land holdings in Third World countries, reducing reliance on back-breaking, labor-intensive hand-hoeing.

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LITERATURE CITED

Beckett, T. H. and E. W. Stoller. 1988. Volunteer corn (*Zea mays*) interference in soybeans (*Glycine max*). Weed Sci. 36:159–166.

Black, A. L. and F. H. Siddoway. 1977. Winter wheat recropping on dryland as affected by stubble height and nitrogen fertilization. Soil Sci. Soc. Am. J. 41:1186–1190.

Campbell, C. A., A. G. Thomas, V. O. Biederbeck, B. G. Mcconkey, F. Selles, D. Spurr, and R. P. Zentner. 1998. Converting from no-tillage to pre-seeding tillage: Influence on weeds, spring wheat grain yields and N, and soil quality. Soil Tillage Res. 46:175–185.

Cardina, J., E. Regnier, and D. Sparrow. 1995. Velvetleaf (*Abutilon theo-*

phrasti) competition and economic thresholds in conventional- and no-tillage corn (*Zea mays*). Weed Sci. 43:81–87.

Crook, T. M. and K. A. Renner. 1990. Common lambsquarters (*Chenopodium album*) competition and time of removal in soybeans (*Glycine max*). Weed Sci. 38:358–364.

Donald, W. W. 1998. Estimating relative crop yield loss due to herbicide damage using crop ground cover or rated stunting, with maize and sethoxydim as a case study. Weed Res. 38:425–431.

Fellows, G. M. and F. W. Roeth. 1992. Shattercane (*Sorghum bicolor*) interference in soybean (*Glycine max*). Weed Sci. 40:68–73.

Harris, T. C. and R. L. Ritter. 1987. Giant green foxtail (*Setaria viridis* var. *major*) and fall panicum (*Panicum dichotomoflorum*) competition in soybeans (*Glycine max*). Weed Sci. 35:663–668.

Hume, L. 1982. The long-term effects of fertilizer application and three rotations on weed communities in wheat (after 21–22 years at Indian Head, Saskatchewan). Can. J. Plant Sci. 62:741–750.

Knake, E. L. and F. W. Slife. 1965. Giant foxtail seeded at various times in corn and soybeans. Weeds 13:331–334.

Knake, E. L. and F. W. Slife. 1969. Effect of time of giant foxtail removal from corn and soybean. Weed Sci. 17: 281–283.

Moyer, J. R. and R. D. Dryden. 1977. Effects of combined applications of triallate or trifluralin with solution nitrogen on wheat, wild oats, and green foxtail. Can. J. Plant Sci. 57:479–484.

Oliver, L. R. 1988. Principles of weed threshold research. Weed Technol. 2: 398–403.

Radosevich, S., J. Holt, and C. Ghersa. 1997. Weed ecology. *In* Implications for Management. 2nd ed. New York: John Wiley & Sons. pp. 163–301.

Rathman, D. P. and S. D. Miller. 1981. Wild oat (*Avena fatua*) competition in soybean (*Glycine max*). Weed Sci. 29:410–414.

Sardi, K. 1996. Effects of fertilizer salts on the germination of corn, winter wheat, and their common weed species. Commun. Soil Sci. Plant Anal. 27:1227–1235.

Schimpf, D. J. and I. G. Palmbald. 1980. Germination response of weed seeds to soil nitrate and ammonium with and without simulated overwintering. Weed Sci. 28:190–193.

Sibuga, K. P. and J. D. Bandeen. 1980. Effects of green foxtail and lamb's-quarters interference in field corn. Can. J. Plant Sci. 60:1419–1425.

Sokal, R. R. and F. J. Rohlf. 1981. Biometry. *In* The Principles and Practice of Statistics in Biological Research. 2nd ed. New York: W. H. Freeman and Co. pp. 232–242 and 348–354.

SPSS. 1998. SPSS Base 8.0 User's Guide and SPSS Applications Guide. Chicago: SPSS, Inc.

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

Williams, C. S. and R. M. Hayes. 1984. Johnsongrass (*Sorghum halepense*) competition in soybean (*Glycine max*). Weed Sci. 32:498–501.

Wilson, R. G. and P. Westra. 1991. Wild proso millet (*Panicum miliaceum*) interference in corn (*Zea mays*). Weed Sci. 39:217–220.

Zimdahl, R. L. 1980. Weed–Crop Competition, A Review. Corvallis, OR: International Plant Protection Center, Oregon State University. pp. 83–93.