Between-Row Mowing Systems Control Summer Annual Weeds in No-Till Grain Sorghum

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In previous research, use of PRE soil residual herbicides was reduced 50% in no-till corn and soybean by banding herbicides over crop rows followed by mowing weeds growing between rows two times. The research goals were (1) to determine whether such between-row mowing systems adequately controlled weeds and prevented grain yield loss in other competitive field crops, such as no-till grain sorghum, and (2) to compare broadcast herbicide treatments with between-row mowing systems. PRE atrazine plus dimethenamid at relative rates of 0.75× and 1× (where 1× = 1.7 plus 1.3 kg ai/ha, respectively) were band-applied over rows shortly after planting followed by two between-row mowings close to the soil surface. In 2 of 3 yr in Missouri, this system controlled giant foxtail and common waterhemp as well as broadcast herbicides in no-till sorghum. In 2 of 3 yr, between-row mowing systems also prevented yield loss in no-till sorghum as well as both broadcast herbicides at the same rates and the weed-free check.

Nomenclature: Atrazine; dimethenamid; giant foxtail, *Setaria faberii* (L.) Beauv. SETVI; common waterhemp, *Amaranthus rudis* Sauer. AMATA; corn, *Zea mays* L. ZEAMX; sorghum, *Sorghum bicolor* (L.) Moench SORVU 'Northup King GS10'and 'Pioneer 84G62'; soybean, *Glycine max* (L.) Merr.

Key words: Alternative weed control, application, banding, cutting, mechanical weed control, nonchemical weed control, reduced rate herbicide.

In 1998, U.S. farmers treated 82% of the 91% of grain sorghum hectareage (''sorghum'' hereafter) receiving herbicides with atrazine to control weeds (USDA-NASS 2004). To address environmental (Logan 1993; Richards and Baker 1993) and economic concerns, weed scientists continue to explore ways to reduce herbicide use in extensively grown field crops such as sorghum (Stahlman and Wicks 2000). Herbicide use can be reduced by (1) decreasing the area treated with herbicides and substituting mechanical weed control methods, (2) reducing herbicide rates and changing application timing, or (3) substituting different herbicides that are applied at lower rates.

This research focused on tactics that decrease the area treated with herbicides by substituting unconventional mechanical weed control methods. It is well established that banding herbicides over crop rows and substituting mechanical cultivation between rows reduced the herbicide-treated area 50% compared with broadcast-applied herbicides (Stahlman and Wicks 2000). In competitive crops such as sorghum, banded herbicides followed by cultivation prevented yield losses due to weeds (Baumann and Weaver 1991; Phillips 1969). In other crops, banding herbicides had environmental benefits that likely also apply to sorghum. For example, in corn, banding PRE atrazine plus metolachlor followed by cultivation decreased both herbicide leaching through the soil profile and herbicide loss in runoff water from fields (Gaynor and Van Wesenbeeck 1995).

Although cultivation can help reduce herbicide contamination of water, cultivation itself has negative environmental effects, and farmers are unlikely to use it widely. Negative effects include soil erosion and increased sediment and nutrient loss in runoff from fields (Blevins et al. 1998). Cultivation also is incompatible with no-tillage residue management, unless specialized cultivators are used (Hanna et al. 2000; Paarlberg et al. 1998). In farmer surveys conducted during the mid-1990s, banding herbicides followed by cultivation was unacceptable to Missouri row crop farmers (Rikoon et al. 1996).

In published research in soybean and corn, PRE herbicide use was reduced 50% by banding herbicides over crop rows and substituting between-row mowing for cultivation (Donald 2000a, 2000b; Donald et al. 2001). Soybean and corn yields of the weed-free checks were statistically indistinguishable from treatments with banded PRE herbicide followed by between-row mowing. Unlike conventional cultivation, between-row mowing systems are compatible with no tillage (Donald et al. 2001). If between-row mowing is properly timed before corn or soybean canopies close, mowing weeds close to the soil surface two times killed most common annual weeds, including giant foxtail, common ragweed (*Ambrosia artemisiifolia* L.) and common waterhemp. If between-row mowers are commercialized as an alternative for cultivation, this alternative weed management system may have potential use in many competitive, upright-growing row crops such as grain sorghum.

Grain sorghum has been successfully produced using no tillage (Bishnoi et al. 1990; Phillips 1969; Stahlman and Wicks 2000; Unger 1999). For example, when rotated after either cover crops of winter wheat (*Triticum aestivum* L.) or crimson clover (*Trifolium incarnatum* L. 'Bigbee'), grain sorghum yielded more under no tillage than under conventional tillage in Alabama (Bishnoi et al. 1990). However, similar tillage systems failed to influence sorghum yields in the Great Plains (Phillips 1969). When row spacings of 45, 60, and 90 cm were compared under no tillage, sorghum yielded most at the narrowest row spacing, presumably because

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seeding rates were greater (Bishnoi et al. 1990; Phillips 1969; Stahlman and Wicks 2000). Nevertheless, narrower row spacing failed to improve weed control in no-tillage sorghum.

The research goals were (1) to determine whether between-row mowing systems adequately controlled weeds and prevented grain yield loss in no-till grain sorghum, and (2) to compare broadcast herbicide treatments with between-row mowing systems. It was hoped that between-row mowing systems could be extended for use from corn and soybean to grain sorghum. In this research, no-tillage sorghum was grown in 53-cm-wide rows, and broadcast PRE herbicide at two rates (i.e., 1× and 0.75× relative rates) were compared with the same herbicides banded over rows followed by mowing between rows two times. The null hypothesis was that grain yields of the weed-free checks would be maximum and statistically indistinguishable for the broadcast herbicide and between-row mowing systems. The amount of between-row weed cover for treatments was expected to be ranked: weed-free checks ≤ treatments < weedy checks. It was hypothesized that sorghum grain yields, weed cover, or weed control would each be indistinguishable from the treatments at both herbicide rates (0.75× or 1×).

MATERIALS AND METHODS

Site, Weather, and Weeds. In 1998, 1999, and 2000, grain sorghum was planted after soybeans at the University of Missouri's Bradford Research and Extension Center in north central Missouri near Columbia (38°53′43.5″N, 92°12′37.9″W, 269 m altitude). The soil was a Mexico silty clay loam (fine, smectitic, mesic Aeric Vertic Epiaqualfs) that had 18% sand, 48% silt, 34% clay, 3.3% organic matter, and pH of 5.5 to 5.8. According to the soil testing lab at the University of Missouri, Columbia, soil pH is the salt pH, and values of pH run approximately 0.5 units lower than the customary water pH values.

Historical weather data were collected at the Bradford center (Figure 1). Because weather data were incomplete at Bradford in 1995 and 2001, weather data from the nearby Sanborn Experimental Field and University of Missouri South Farm were substituted in 1995 and 2001, respectively, for calculation of long-term averages. Daily heat units are defined as [(maximum temperature – minimum temperature)/2 – base temperature] in degree C days. Heat sums were calculated by summing daily heat units from sorghum planting until harvest using a base temperature of 10 C.

Shepherd's purse [*Capsella bursa-pastoris* (L.) Medik. CAPBP], fleabane species (*Erigeron* spp.), and horseweed [*Conyza canadensis* (L.) Cronq. ERICA] were the major winter annual weeds present. Giant foxtail was the major summer annual grass weed present. After giant foxtail, most remaining weed cover consisted of the following summer annual broadleaf weeds: common waterhemp, common ragweed, and prickly sida (*Sida spinosa* L. SIDSP).

Agronomic Practices. For controlling winter annual weeds before no-till planting, glyphosate at 0.84, 2.24, and 1.12 kg ae/ha plus ammonium sulfate at 3.36 kg/ha were broadcast over the site in spring of 1998, 1999, and 2000, respectively (Table 1). In 1998, 1999, and 2000, glyphosate was applied using a tractor-mounted sprayer operated at 4.8, 2.4, and 2.4 km/h, respectively, at a hydraulic pressure of 207 kPa to apply spray volumes of 83, 159, and 159 L/ha of water, respectively, with flat fan spray nozzles.[1] The nozzle spacing on the boom was 51 cm, and the boom height was about 61 cm above the soil surface.

Sorghum was fertilized with N-P-K for a grain yield goal of 5,650 kg/ha, on the basis of soil tests and recommendations of the University of Missouri soil testing lab. N-P-K was deep-banded using a no-till grain drill[2] at [157-157-157], [87-121-121], and [91-91-91] kg/ha, respectively. 'Northup King GS10' hybrid sorghum seed, which had been treated with captan, pirimiphos-methyl, metalaxyl, and fluxofenim, were planted 3 to 4 cm deep in 53-cm rows at 342,250 seeds/ha in 1998 and 358,150 seeds/ha in 1999 (Table 1 and Figure 1). In 2000, 'Pioneer 84G62' seed, which had been treated with imidacloprid and fluxofenim, were planted at 341,870 seeds/ha similarly.

Treatments. Treated plots measured 3 by 9.1 m. For PRE broadcast treatments, atrazine plus dimethenamid were applied at relative rates of 1× and 0.75×, where 1× = 1.7 plus 1.3 kg ai/ha, respectively (Table 1 and Figure 1). A backpack sprayer was operated at 4.8 km/h using compressed CO_2 at 207 kPa to apply spray volumes of 84 L/ha of water through flat fan nozzles.[3] For broadcast application, nozzles were spaced 76.2 cm apart on the boom, and the boom height was about 86 cm above the soil surface.

In between-row mowing systems, the same PRE herbicides were banded over rows at the same two relative rates followed by two mowings close to the soil surface between rows after weeds became tall enough to mow. The herbicide band width was 50% of the row width (i.e., 27-cm-wide bands centered over 53-cm rows) (Table 1 and Figure 1). In 1998, 1999, and 2000, a backpack sprayer was operated at 4.8 km/h using compressed CO_2 at 207, 207, and 276 kPa to band-apply spray volumes of 84, 84, and 94 L/ha of water, respectively, with even nozzle tips.[3] For band application, nozzles were spaced 53 cm apart on the boom, and the boom height was about 15 cm above the soil surface.

The bands of PRE herbicides kept sorghum rows free of weeds by the time that between-row weeds were first mowed at about 3 cm above the soil surface (Table 1). When they were first mowed, the heights of the chief weeds varied among years (Figure 2). Weeds were mowed again just before sorghum canopy closure. The mowing width of the plastic cord mower[4] was 46 cm, leaving about 3.5 cm unmowed on either side of sorghum rows. The edge of the mowed region slightly overlapped the edge of the sprayed zone.

The experiment included weedy and weed-free checks. Before planting, glyphosate was broadcast over the entire site to kill winter annual weeds (see above). In weedy checks, summer annual weeds were uncontrolled. In ''weed-free'' checks, summer annual weeds growing between rows were shallowly hoed close to the soil surface to avoid pruning sorghum roots, and in-row weeds were hand pulled and hoed several times during the growing season (Table 1). To avoid yield loss from crop damage during weeding, hoeing was ended in late summer. In competition research, late-emerging

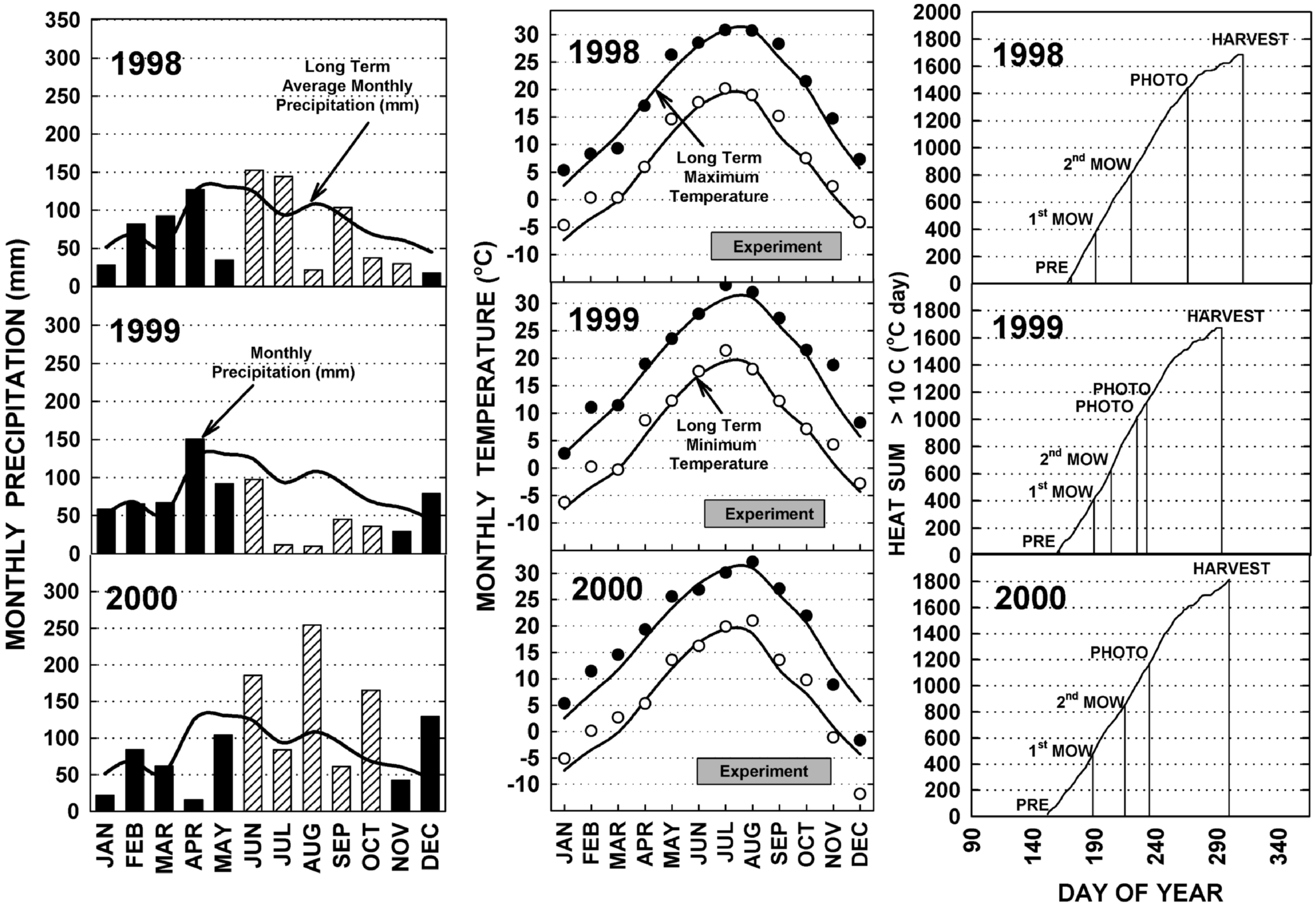

Figure 1. The monthly precipitation (bars) and long-term average monthly precipitation (lines) are graphed vs. month of the year in 1998 to 2000 (left panels). Monthly average maximum and minimum air temperatures (solid and open circles, respectively) and long-term averages (lines) are graphed vs. month of the year (middle panels). Cumulative heat sums > 10 C (i.e., growing degree days) after planting are graphed vs. day of the year (right panels). The 9-yr averages were from 1993 to 2001. The length of the experiments is indicated by either hatched bars (left panels) or a horizontal bar (middle panels). Abbreviations: MOW, between-row mowing imposed; PHOTO, photographs taken.

Table 1. Dates for field operations, treatments, or measurements.

Field operations, treatments, or measurements	1998 Date	1998 DAP[a]	1999 Date	1999 DAP[a]	2000 Date	2000 DAP[a]
Broadcast glyphosate	May 27	–	May 19	–	May 16	–
Plant sorghum and inject N-P-K fertilizer	June 16	0	June 8	0	May 31	0
Apply PRE atrazine plus dimethenamid	June 19	3	June 10	2	June 6	6
Sorghum first emerges	June 22	6	June 13	5	June 11	11
Measure sorghum stand	August 10	55	July 2	24	August 7	68
Mow between-row weeds	July 9	23	July 8	30	July 7	37
Remow between-row weeds	August 7	52	July 22	44	August 2	63
In weed-free check plots:						
Hoe and hand pull weeds:	July 14	28	July 7	29	July 7	37
Rehoe and hand pull weeds	August 7	52	July 21	43	July 10–11	–
Rehoe and hand pull weeds	August 21	66	–	–	August 3–4	–
Photograph between-row weed cover	September 22	98	August 12	65	August 22	83
Photograph overrow weed cover	September 22	98	August 20	73	August 22	83
Rate weed control	–	–	August 24	77	August 22	83
Harvest sorghum	November 6	143	October 20	134	October 26	148

[a] DAP, days after planting.

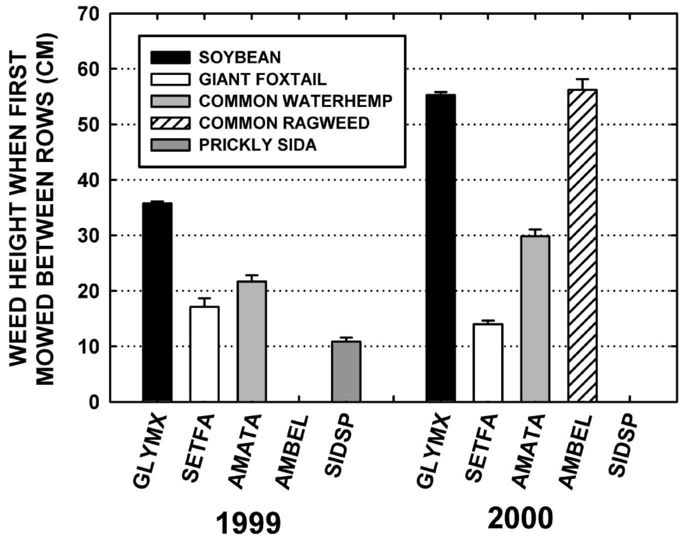

Figure 2. Grain sorghum and weed heights (cm, means ± standard error) when weeds growing between rows were first mowed in 1998 to 2000.

weeds do not reduce grain sorghum yields (Burnside and Wicks 1969).

Measurements. After full emergence, sorghum stands were measured in 1.8-m lengths in the two center rows of each plot. At mid-season, weed control was visually evaluated on the basis of a scale of 0% (no control) to 100% (complete kill). After cutting borders at either end of all plots, sorghum was combine-harvested from an area measuring 1.5 by 8.2 m, and grain yields were adjusted to 13% moisture content.

To measure treatment effectiveness, projected ground covers of between-row grass, broadleaf, and total weeds (i.e., grass plus broadleaf weeds), but not crop cover, were measured from photographs taken between crop rows (Table 1). Sorghum foliage overhanging and obscuring the between-row region was pulled back with 1-m^2 wooden frame panels covered with black cloth, and an orange dowel was extended at a right angle out from the crop row just above the soil surface toward the row middle to mark the herbicide band width in the photographs. Four between-row photographs per plot were taken vertically (i.e., camera facing toward the soil surface) with a digital camera[5] at a height of 132 cm. Each photograph (640 by 512 pixels per photograph) corresponded to 1.06 m^2 at the soil surface on the basis of photographs of a 30- by 30-cm orange calibration plate. In 1999 and 2000, four additional photographs per plot were taken over rows for measuring over-row cover above the sorghum foliage. Image analysis software[6] was used to crop between-row zones and automatically superimpose a 20 by 20 pixel grid over each between-row photograph. Weed cover was calculated as a percentage (i.e., the number of grid intersections that were either grass or broadleaf weed cover divided by the total number of grid line intersections per cropped photograph). Four measurements per plot were averaged for reporting weed cover.

Statistical analysis. Treatments were applied in a randomized complete block experimental design with four blocks, and blocking was based on slope position and weed ground cover observed in preceding years (Hoshmand 1994). For each year separately, sorghum grain yields, rated weed control, weed cover, and maximum canopy height were subjected to ANOVA using statistical software.[7] Means were separated by Fisher's protected LSD test at P = 0.05.

Results and Discussion

Yield. In 1998, 1999, and 2000, no-till sorghum stands were 100, 68 and 80% of planting intentions, respectively (see Materials and Methods). In these 3 yr, no-till grain yields of the weed-free checks were 71, 66, and 73% of the yield goal for which the experiment was fertilized, respectively (i.e., 5,650 kg/ha) (Figure 3). In all 3 yr, yields of weed-free no-till sorghum (4,030, 3,720, and 4,120 kg/ha, respectively) were less than average Missouri sorghum yields under conventional tillage (i.e., 5,580, 4,780, and 6,320 kg/ha, respectively) (Missouri Agricultural Statistics Service 2004). The reasons why the weed-free no-till sorghum never achieved its planned yield goal are unclear. Mechanical and manual weed control was imposed as needed in a timely fashion and controlled weeds. University of Missouri fertility recommendations for grain sorghum, which were used, were developed for conventionally tilled grain sorghum and may need adjustment upward for no tillage. Although sorghum is more drought tolerant than many other field crops (Rooney 2000), no-till grain yields of weed-free checks were similar in years of both below-average (i.e., 1998 and 1999) and above-average growing-season rainfall (i.e., 2000) (Figures 1 and 3). Consequently, weed-free yields of no-till sorghum were unrelated to year-to-year variation in either stand or seasonal rainfall.

Weeds limited yields in 2 of 3 yr, since yields of weed-free checks were significantly greater than weedy checks in 2 of 3 yr (i.e., 1998 and 2000) (Figure 3). In these years, yields of weedy checks were 67 and 59% of the weed-free checks, respectively. In 1998, the following three treatments controlled weeds, and their yields were statistically indistinguishable from each other and the weed-free check: the broadcast PRE herbicides at 1× and the two between-row mowing systems (Figure 3). In 2000, all four treatments were statistically indistinguishable from one another and the weed-free check.

In contrast, in 1 of 3 yr (i.e., 1999), weeds did not reduce yields; the yields of the weedy check, weed-free check, and treatments were statistically indistinguishable from each other in 1999 (Figure 3). This result was unexpected because weed cover was high (Figure 3), and the site had been heavily infested with summer annual weeds that greatly reduced corn and soybean yields for at least 6 previous years (unpublished data).

Weed control, weed cover, and maximum weed canopy height. In 1998, the values for rated control of total weeds, giant foxtail, and broadleaf weeds for all four treatments were statistically indistinguishable from their respective weed-free checks and all exceeded 90% (Figure 3). However, in 1999, values of rated control for total weeds, giant foxtail, and

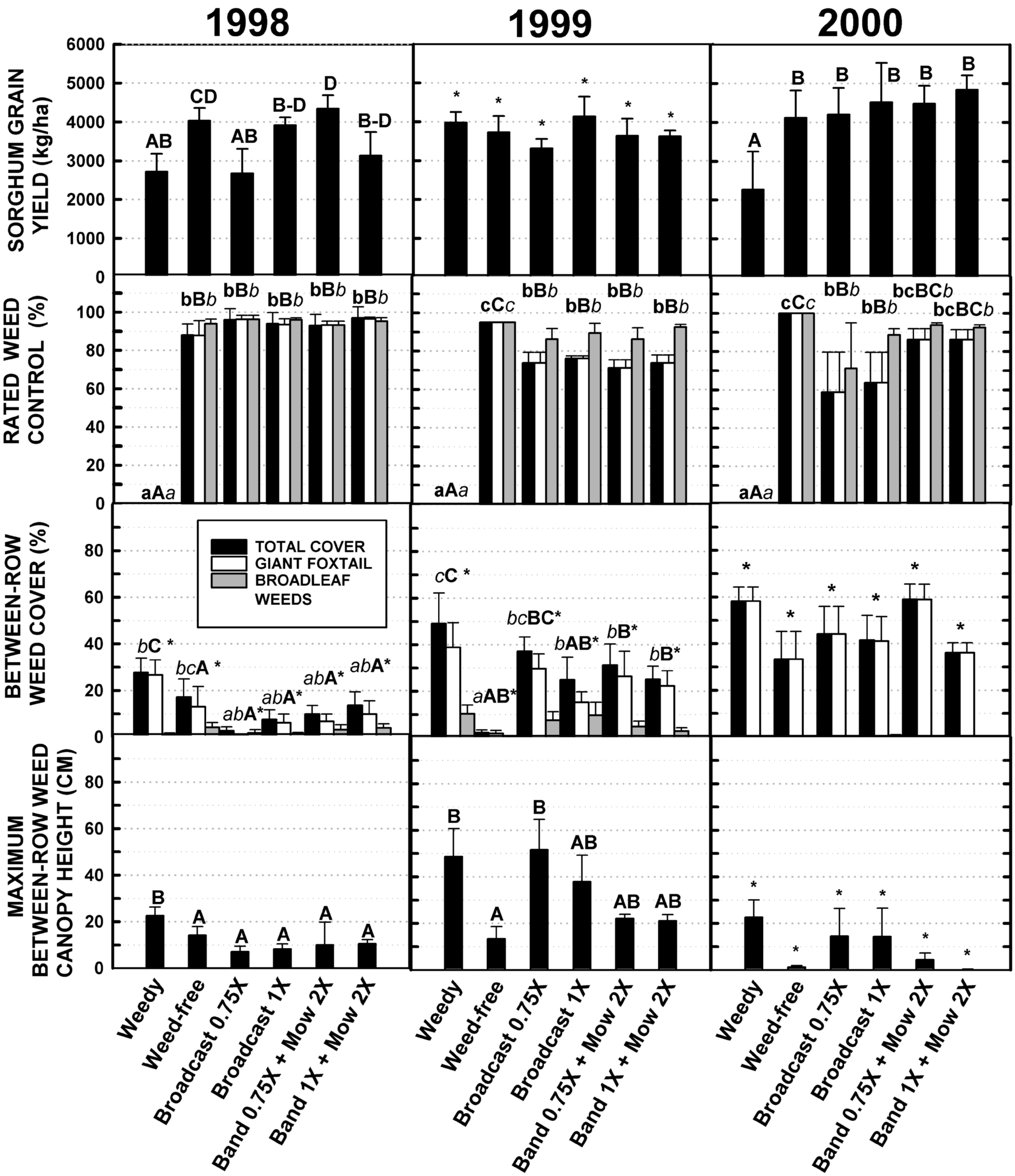

Figure 3. Sorghum grain yield (kg/ha), rated weed control (%), between-row weed cover (%) measured from photographs, and maximum weed canopy height (cm) between rows are graphed vs. weed management treatment for 1998, 1999, and 2000. Both weed control rating and weed cover subdivided into total weeds, giant foxtail, and broadleaf weeds are indicated by different degrees of shading (legend box). Means (± standard errors) are presented and those means for each variable in a year followed by the same letter (different fonts or cases for different variables separately) were not different at P = 0.05 by Fisher's protected LSD. *, nonsignificant.

broadleaf weeds of all four treatments were less than their respective weed-free checks and were indistinguishable from one another. In 2000, total weed control was statistically indistinguishable for all four treatments. However, weed control with mowing systems also were indistinguishable from the weed-free check and outperformed PRE herbicides by about 20%. In 2000, values for giant foxtail and broadleaf weed control of all four treatments were less than their respective weed-free checks. From separate observations of total weed, giant foxtail, and broadleaf weed control over and between rows, rated weed control of whole plots was due chiefly to rated control between rows (data not presented). Values of rated total weed, giant foxtail, and broadleaf weed control over rows of all treatments were greater than the respective weedy checks, and treatments were indistinguishable from one another in all 3 yr (data not presented).

The effects of between-row mowing treatments on rated weed control were the inverses of effects on between-row weed cover (Figure 3). Pearson correlation coefficients between rated total weed control and between-row total weed cover were −0.51, −0.76, and −0.52 in 1998, 1999, and 2000, respectively. Compared with visually rated weed control, weed cover of total weeds, giant foxtail, and broadleaf weeds provided different information about weed response to treatment and the factors limiting grain yields. Rated control can be interpreted as a subjective judgment of whether treatments would be visually acceptable to farmers. Rated control provided no information on whether giant foxtail was more common than broadleaf weeds, and whether giant foxtail was better related to grain yield loss than were broadleaf weeds. Likewise, rated control for weedy checks was taken as 0% in all years, and provided no information on differences in weed populations among years.

In late summer of 1998, 1999, and 2000, values of total weed cover between rows in the weedy checks were 27, 49, and 58%, respectively (Figure 3). In contrast, in 1999 and 2000, values of total weed cover over rows were 15% and 8%, respectively; in 1998, weed cover over rows was not measured. Weed cover both over rows and between rows was chiefly giant foxtail in 1998 and 1999, and almost entirely giant foxtail in 2000. Consequently, giant foxtail growing between rows was largely responsible for reducing grain yields of no-till sorghum in 1998 and 2000, rather than broadleaf weeds. This conclusion is not obvious from rated control of giant foxtail and broadleaf weeds. In fact, broadleaf weed "control" was more apparent than real because broadleaf weeds accounted for little total weed cover in any year (Figure 3), and sorghum and giant foxtail interference likely suppressed broadleaf weed seedlings' growth.

By late summer in 2 of 3 yr (i.e., 1998 and 1999) following between-row mowing treatment, both between-row total weed cover and maximum weed canopy height were less than in the weedy checks (Figure 3). All four treatments reduced both weed cover and maximum weed canopy height in 1998 and weed cover in 1999 to about the same extent below the weedy check. However, in 1999 the broadcast herbicides failed to reduce the maximum weed canopy height compared with the weedy check, in contrast to the between-row mowing treatments. Even though 1999 had below-average seasonal rainfall, early-season rainfall probably was adequate to "activate" the PRE herbicides. For example, values of overrow total weed cover for both broadcast herbicide treatments were low and about 6% in 1999. In 1999, it is more likely that lack of mid-season rainfall (Figure 1) limited sorghum canopy closure and shading, which subsequently limited crop interference with between-row weed cover development (Figure 3). For between-row total weed cover and maximum weed canopy height in 2000, differences among treatments were nonsignificant, but treatments were ranked similarly to 1998 and 1999. After either broadcast herbicide or between-row mowing treatment, most between-row total weed cover was giant foxtail, as in the weedy check (Figure 3). Mowing controlled annual broadleaf and grass weeds differently. The first mowing killed the few annual broadleaf weeds present, chiefly common waterhemp, in addition to common ragweed and prickly sida. In 1998 and 1999, but not 2000, common waterhemp and prickly sida were the chief broadleaf weeds to produce broadleaf weed cover by late summer in no-till sorghum. After one mowing, giant foxtail regrew from tiller buds present in the crown close to the soil surface, below the mowing height. In published research in soybean and corn (Donald 2000a, 2000b; Donald et al. 2001), a second mowing killed giant foxtail growing between rows. After two mowings in no-till sorghum, giant foxtail regrew somewhat to produce greater cover than previously reported in either no-till corn or soybean, but still less than the weedy check in 2 of 3 yr. Shading likely limited giant foxtail recovery (Santelmann et al. 1963) after a second mowing in all three crops. However, the sorghum canopy closed less completely than either corn or soybean canopies and consequently shaded the soil surface less intensely. Less complete canopy closure and shading likely allowed giant foxtail to recover from mowing in sorghum more than in corn (Figure 3).

In between-row mowing systems, the timing of weed emergence relative to the timing of crop planting and subsequent mowing likely contributed to greater weed cover between rows in no-till sorghum (Figure 3), compared with no-till corn (Donald et al. 2001). In Missouri and the southern Corn Belt, the period for planting corn generally precedes both the normal period for planting sorghum (Missouri Agricultural Statistics Service 2004) and the seasonal flushes and peaks of emergence for most major summer annual grass and broadleaf weeds (Buhler and Hartzler 2001; Hartzler et al. 1999). Most weed emergence also precedes sorghum planting. Glyphosate treatment before planting no-till corn chiefly controls winter annual weeds and the early flushes of summer annual broadleaf weeds. Consequently, no-till corn becomes infested with weeds that emerge after glyphosate application and corn planting. In contrast, glyphosate treatment before planting sorghum chiefly controlled both established winter annual weeds and most of the major emergence of summer annual broadleaf and grass weeds. After glyphosate application at no-till sorghum planting, fewer weeds likely emerged because weed seed banks near the soil surface had been depleted and environmental conditions become unfavorable for both breaking weed seed dormancy and allowing successful weed emergence during late summer. In addition to competition through shading, sorghum also may suppress weed cover growth by allelopathy

(Cheema et al. 2004; Mikulas 1984; Nimbal et al. 1986), although documented proof for allelopathy is limited in the growing sorghum crop. Most data concern sorghum allelopathy to later-planted rotational crops.

Values of between-row total weed cover in corn were greater than 80% in weedy checks at mid-season at the site (unpublished data). In contrast, in late summer in no-till sorghum, values for between-row total weed cover in the weedy checks were 27, 49, and 58% in 1998, 1999, and 2000, respectively, (Figure 3). Most of this weed cover was giant foxtail in both crops and likely corresponds to the tail of the seasonal peak for giant foxtail emergence (Buhler and Hartzler 2001; Hartzler et al. 1999). Spraying glyphosate before planting no-till sorghum well after most summer annual weeds have emerged likely contributed to the observed suppression of weed cover by sorghum, rather than allelopathy (Figure 3). In weedy checks in late summer in 1999, no-till sorghum tolerated 49% weed cover without yield loss; 49% weed cover does not represent much weed suppression by supposedly allelopathic sorghum. These observations are more consistent with sorghum tolerance of weeds (i.e., yield production in the presence of weeds), rather than sorghum suppression of weeds by either competition or allelopathy.

Sources of Materials

[1] Teejet flat fan spray nozzle tips 6501 SS, Spraying Systems Co., Wheaton, IL 60187.

[2] No-till grain drill model 107, Haybuster Manufacturing, Box 1950, Jamestown, ND 58401.

[3] Teejet even fan spray nozzle 8001 EVS, Spraying Systems Co., Wheaton, IL 60187.

[4] Ryobi weed trimmer (model 780r or 790r), Ryobi Outdoor Products, 550 North 54th St. Chandler, AZ 85226.

[5] Olympus D 600L and D620L digital cameras, Olympus America Inc., Two Corporate Center Dr., Melville, NY 11747-3157.

[6] Sigma Scan Pro version 5 software, SPSS Science, SPSS Inc., 233 South Wacker Drive, 11th Floor, Chicago, IL 60606-6307.

[7] SPSS version 12 software, SPSS Inc., 233 South Wacker Drive, 11th Floor, Chicago, IL 60606-6307.

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