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Between-row mowing + in-row band-applied herbicide for weed control in *Glycine max*

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Most farmers now rely on herbicides and, to a lesser extent, cultivation to control weeds in *Glycine max* in the Midwest. However, the general public is concerned that widely used herbicides will contaminate surface and groundwater. Alternative ways to control weeds in field crops are needed to reduce or prevent herbicide contamination of surface and groundwater. A new between-row-mowing weed management system that consists of band-applied herbicides over crop rows + two or more between-row mowings was tested in *G. max* over 6 yr in Missouri. Mowing weeds close to the soil surface two or more times between crop rows killed or suppressed annual grass and broadleaf weeds, chiefly *Setaria faberi*, *Ambrosia artemisiifolia*, and *Amaranthus* spp., if properly timed. Shading by crop canopy closure contributed to weed suppression in this weed management system. *G. max* yield also could not be distinguished from weed-free check plots and was greater than the weedy check plots. Herbicide use was reduced 50% by banding because only 50% of the field area was sprayed. The between-row-mowing weed management system may have use in environmentally sensitive areas to help reduce soil erosion or water contamination by herbicides.

Nomenclature: Common ragweed, *Ambrosia artemisiifolia* L. AMBEL; giant foxtail, *Setaria faberi* Herrm. SETFA; *Amaranthus* spp., waterhemp spp.; soybean, *Glycine max* (L.) Merr. 'Morsoy 9137' and 'Pioneer 9381'.

Key words: Band application, cutting, mowing, trimming, defoliation, nonchemical weed control, reduced herbicide rate.

Most farmers now rely on herbicides and, to a lesser extent, cultivation to manage weeds in *Zea mays* L. (corn) and *G. max* (soybean) in the Midwest (Anonymous 1999). But, both herbicides and cultivation can have negative environmental effects, although the general public is most concerned about herbicide use. Cultivation can increase soil-bound nutrient and sediment loss in runoff, and herbicides can contaminate surface and groundwater (Brock 1982; Daniel et al. 1998; Logan et al. 1987; Mutchler and Greer 1984; Pelly 1998; Richards and Baker 1993). Both cultivation and herbicide use must be reduced to minimize these unanticipated, negative environmental effects (Logan 1993; Logan et al. 1987). Profitable, alternative weed management systems are needed to help farmers solve these pressing environmental concerns without greatly changing current farming practices.

It has been long known that either broadcast or band-applied herbicides over crop rows followed by field cultivation controls weeds and prevents yield loss (Logan 1993). But, banding herbicides reduced herbicide use and loss in runoff water as well as herbicide leaching into soil (Gaynor and Van Wessenbeeck 1995; Gaynor et al. 1995). Banding and field cultivation are usually used together. However, cultivation can have negative environmental effects and, in general, is incompatible with no-tillage farming methods.

Weeds must be removed from row crops before they begin to reduce crop yield. Research shows that there is a limited period after crop emergence when weeds can grow in some crops without reducing yield (Oliver 1988; Radosevich et al. 1997; Zimdahl 1980). After this period ends, if weed removal is progressively delayed, yield declines to a low level. Alternative weed management systems must either kill weeds or suppress them long enough so that the crop gains a competitive advantage and weeds do not reduce yield.

The proposed new between-row (BR)-mowing weed management system consists of (1) planting a competitive crop, *G. max;* (2) banding herbicide(s) over crop rows according to recommendations in U.S. Environmental Protection Agency (EPA) registration labels; and (3) mowing weeds between crop rows close to the soil surface before crop canopy closure (Figure 1). At the start, it was unknown whether this weed management system would work. It was also unknown how many mowings were required and how to properly time mowing to prevent weeds from reducing *G. max* yield.

The goal of these experiments was to determine whether different BR-mowing weed management systems controlled weeds in *G. max* and yielded at least as well as weed-free checks and more than weedy checks. In the first two experiments, the numbers (i.e., one to five per growing season) and timing of BR mowings were varied between *G. max* planting and canopy closure to create different weed management systems. In experiment 1, the first mowing was progressively delayed after planting, but all mowing was finished before canopy closure. In experiment 2, all BR mowings were begun simultaneously after planting but were ended at progressively later times before canopy closure in different BR-mowing weed management systems. These exploratory experiments suggested that if herbicide was band applied in crop rows, then two mowings were

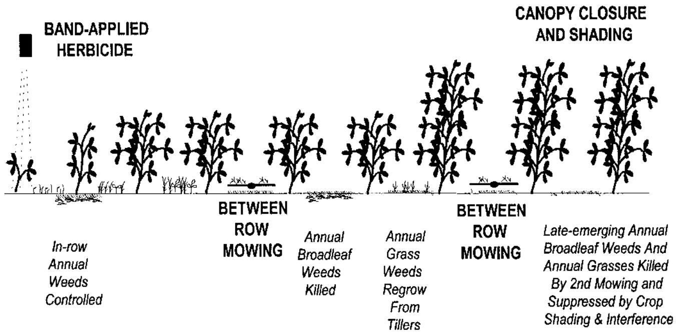

FIGURE 1. Diagram of the components of the between-row mowing weed management system in *G. max* over time until crop canopy closure.

required to prevent weeds from reducing *G. max* yield and that weeds should be mowed when they were first tall enough to be mowed (> 3 to 3.5 cm) followed by a second mowing shortly before *G. max.* canopy closure. This BR-mowing (2×) weed management system was evaluated in experiment 3.

Materials and Methods

Common Agronomic Practices

Experiments 1 and 2 were repeated from 1993 to 1995, and experiment 3 was repeated from 1996 to 1998, at the University of Missouri's Bradford Experimental Farm near Columbia (lat 38°53′43.5″N, long 92°12′37.9″W, 883 m altitude). The soil was a Mexico silt loam (fine, smectitic, mesic Aeric Vertic Epiqualfs) with 18 to 20% sand, 46 to 48% silt, 34% clay, 2.7 to 3.3% organic matter; cation exchange capacity of 13.2 to 20.5 meg 100 g^{-1}; and pH of 5.3 to 5.8. Field operation dates for treatments and measurements are summarized in Table 1.

Experiments were repeated on adjacent sites in a *Z. mays*–*G. max* rotation started in 1992. The site was either chisel or disc plowed (Table 1). Fertilizers were broadcast before planting and incorporated by disc harrowing and cultipacking for seedbed preparation. In experiments 1 and 2, N-P_2O_5-K_20 were applied at 0-56-90 kg ha^{-1}, 0-38-33 kg ha^{-1}, and 0-40-28 kg ha^{-1} in 1993, 1994, and 1995, respectively, for a yield goal of 2,690 kg ha^{-1} in 1993 and 1994 and 3,020 kg ha^{-1} in 1995, based on soil tests and recommendations of the University of Missouri soil testing lab. In experiment 3, N-P_2O_5-K_20 were applied at 0-84-84 kg ha^{-1}, 0-73-90 kg ha^{-1}, and 0-84-84 kg ha^{-1} in 1996 to 1998, respectively, for a yield goal of 2,690 kg ha^{-1}.

In experiments 1 and 2, *Rhizobium*-treated 'Pioneer 9381' *G. max* seed were planted in 76-cm rows 1.3 to 1.9 cm deep with a four-row planter at 370,000, 370,000, and 420,200 seeds ha^{-1} in 1993, 1994, and 1995, respectively (Table 1). Planting was 1 mo later in 1995 than in either 1993 or 1994 because of untimely rainfall (Figure 2). In experiment 3, 'Morsoy 9137' *G. max* seed were planted at 356,000, 389,000, and 340,000 seeds ha^{-1} in 1996 to 1998, respectively, much like the first two experiments.

Weather data were collected at the Bradford Experimental Farm in 1993, 1994, and 1996 to 1998, but data from the Sanborn Experimental Field in Columbia were substituted in 1995 because automated weather equipment failed at the Bradford Farm (Figure 2).

Hoed, Weed-Free, and Weedy Check Plots

Each experiment included an untreated weedy check and a hoed, weed-free check. Weeds present before planting were controlled by seedbed preparation in spring. In weed-free checks, weeds were hand pulled and hoed in crop rows, and weeds were hoed between crop rows several times during the growing season as needed (Table 1).

Weeds Present

Setaria faberii accounted for most weed ground cover. *Ambrosia artemisiifolia* L. and *Amaranthus* sp. were the most common annual broadleaf weeds present. *Abutilon theophrasti* Medik. (velvetleaf), *Ambrosia trifida* L. (giant ragweed), *Chenopodium album* L. (common lambsquarters), *Cyperus esculentus* L. (yellow nutsedge), *Polygonum pensylvanicum* L. (Pennsylvania smartweed), *Polygonum persicaria* L. (ladysthumb smartweed), and *Xanthium strumarium* L. (common cocklebur) were sparse.

The BR-Mowing Weed Management System

Between-Row Mowing

Weeds were controlled between 76-cm-wide *G. max* rows by close mowing with a plastic cord mower[1,2] operated about 2.5 to 3 cm above the soil surface (Table 1). The BR-mowing width was 60 cm, leaving an unmowed region about 7.6 cm wide next to each crop row. Unless starting time for mowing was a treatment (experiment 1), mowing was started when weeds were 7.6 to 15.2 cm tall and was repeated two (experiment 3) or more times (experiments 1 and 2) throughout the growing season, as needed, to control subsequent weed growth when it became about 7.6 to 15.2 cm tall (Figure 3; Table 1). Final mowing usually preceded *G. max* canopy closure (experiments 1 and 3; Table 1).

In-Row (IR) Band-Applied Herbicide

In experiments 1 and 2, metolachlor at 2.24 kg ai ha^{-1} was applied preemergence (PRE) soon after planting, and thifensulfuron was applied postemergence (POST) at 17.5 g ai ha^{-1} with nonionic surfactant at 0.25% (vol. vol.$^{-1}$) of the spray volume, according to the U.S. EPA registration labels (Table 1). Both metolachlor and thifensulfuron were applied in 38-cm bands over the 76-cm-wide crop rows with a bicycle wheel sprayer operated at 3.2 to 4.8 km h^{-1}. Spray volumes of 130 to 136 L ha^{-1} were applied with even flat fan nozzles[3] at 275 kPa.

In experiment 3, POST thifensulfuron 17.5 g ai ha^{-1} + quizalofop at 0.56 kg ai ha^{-1} + nonionic surfactant at 0.125% (by vol.) were band applied for annual and broadleaf weed control (Table 1). Herbicides were sprayed in 38-cm-wide bands over crop rows with a backpack sprayer operated at 2.2 km h^{-1} using compressed CO_2 at 276 kPa in a spray volume of 160 L ha^{-1} water with flat fan nozzles.[3] Because ALS-herbicide-resistant *A. artemisiifolia* and *Amaranthus* sp. were suspected in 1997, herbicides were changed in 1998 to acifluorfen + sethoxydim + crop oil concentrate

Table 1. Dates of field operations and measurements.

Field operation or measurement	Experiments 1 and 2			Experiment 3		
	1993	1994	1995	1996	1997	1998
Disc or chisel plow experimental site	5/12	10/23	4/4	5/20	5/14	5/29
Fertilize plots with phosphorous and potassium	5/17	5/11	6/14	5/20	5/8	5/14
Spring seedbed preparation						
Disk plow to incorporate fertilizer	5/17	—	—	5/20	5/13	5/14
Field cultivate to incorporate fertilizer	—	5/18	6/15	—	—	—
Plant *G. max*	5/17	5/19	6/19	5/22	5/14	5/29
Apply preemergence (PRE) metolachlor	5/24	5/21	6/22	—	—	—
Rotary hoe site to break soil crust	5/27	—	—	—	—	—
G. max emergence first observed	5/28	5/25	6/26	5/29	5/27	6/7
Apply insecticide to control bean leaf beetles	—	5/5	—	—	—	—
Measure *G. max* stand	6/10	6/10	6/30	—	—	—
Apply postemergence (POST) Thifensulfuron	6/17	6/13	7/10	—	—	—
Apply POST thifensulfuron + quizalofop	—	—	—	6/13	6/30	—
Apply POST aciflourfen + bentazon	—	—	—	—	—	6/26
Hand pull and hoe weeds in check plots	6/23	6/13–15	7/14	6/20	7/2	6/22
	6/30	6/23	7/21	7/10	7/10	7/1
	7/13	7/7	7/26	—	7/23	7/14
	7/21	7/14–15	8/15	—	7/29	7/30
Experiment 1						
First time of mowing started	6/23	6/13	7/14	—	—	—
Removed first time of mowing	6/30	6/23	7/21	—	—	—
Removed first time of mowing	7/13	7/7	7/26	—	—	—
Removed first time of mowing	7/21	7/14–15	8/2	—	—	—
Removed first time of mowing	—	7/21	8/16	—	—	—
Second time of mowing started	6/23	6/23	7/21	—	—	—
Removed second time of mowing	6/30	7/7	7/26	—	—	—
Removed second time of mowing	7/13	7/14–15	8/2	—	—	—
Removed second time of mowing	7/21	7/21	8/16	—	—	—
Third time of mowing started	7/13	7/7	7/26	—	—	—
Removed third time of mowing	7/21	7/14–15	8/2	—	—	—
Removed third time of mowing	—	7/21	8/16	—	—	—
Fourth time of mowing started	7/21	7/14–15	8/2	—	—	—
Removed fourth time of mowing	—	7/21	8/16	—	—	—
Fifth time of mowing started	—	7/21	8/16	—	—	—
Experiment 2						
Mowing started at the same time on treatments	6/23	6/13	7/14	—	—	—
Mowing (mowed 1×) ends on:	6/23	6/13	7/14	—	—	—
Mowing (mowed 2×) ends on:	6/30	6/23	7/21	—	—	—
Mowing (mowed 3×) ends on:	7/14	7/7	7/26	—	—	—
Mowing (mowed 4×) ends on:	7/21	7/14–15	8/2	—	—	—
Mowing (mowed 5×) ends on:	—	7/21	8/16	—	—	—
Experiment 3						
First mowing	—	—	—	6/27	6/27	6/23
Final mowing	—	—	—	7/22	7/22	7/30
Photograph weed cover	7/21–23	8/8–9	8/25	8/6	7/30	8/11
Visually rate weed control	7/23	8/8	8/25	7/25	8/1	8/7
	10/8	10/3	10/5	10/1	9/29	10/13
Harvest *G. max*	10/26	10/6	11/9	10/7	10/3	10/16

at 0.56 + 0.43 kg ai ha^{-1} + 2.3 L ha^{-1} (Table 1). Herbicides were sprayed in 38-cm-wide bands over crop rows with a backpack sprayer with flat fan nozzles[4] operated at 4.8 km h^{-1} using compressed CO_2 at 207 kPa in a spray volume of 110 L ha^{-1} water.

Experiment 1—Mowing Started Progressively Later After Planting but Before *G. max* Canopy Closure

Mowings in different BR-mowing weed management systems were started progressively later after *G. max* planting but before *G. max* canopy closure (Figure 3; Table 1). Weed-free *G. max* height and *S. faberi* heights at herbicide treatment and initial mowing are graphed (Figure 4). Mowing was repeated after weed regrowth was 7.6 to 15.2 cm tall, so that those treatments, which were started earliest, were mowed most often (Figure 3; Table 1). In experiments 1 and 2, different BR-mowing weed management systems are identified in terms of either days after planting when first mowed (experiment 1) or when mowing ended (experiment 2), for brevity. However, number of mowings also varied for different timings of mowing (i.e., timing and numbers were confounded) (Figure 3).

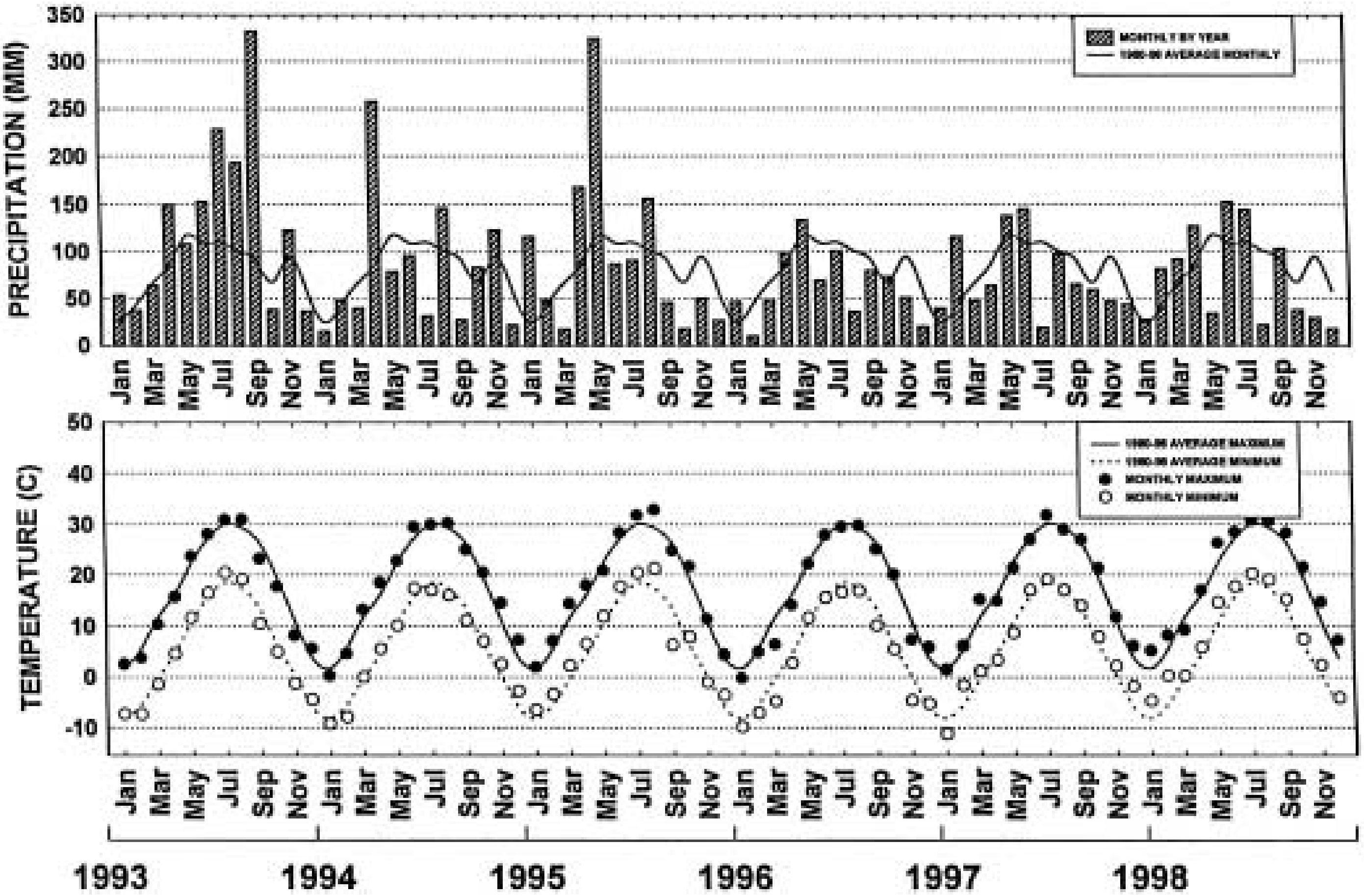

FIGURE 2. Monthly precipitation, maximum and minimum air temperature as well as long-term (1980–1998) average monthly precipitation, maximum air temperature, and minimum air temperature graphed versus time for experiments 1 and 2 (1993–1995) and experiment 3 (1996–1998).

Experiment 2—Mowing Started at the Same Time After Planting and Finished at Various Times Before *G. max* Canopy Closure

All BR-mowing weed management systems were first mowed simultaneously after planting when weeds became about 7.6 to 15.2 cm tall, but mowing in different weed management systems was finished at progressively later times after planting but before canopy closure (Figure 3; Table 1). Weed-free *G. max* height and weed height at herbicide treatment or when first mowed are graphed (Figure 4). Those BR-mowing weed management systems in which mowing was finished later were mowed most often (Figure 3).

Experiment 3—BR-Mowing (2×) Weed Management System

The treatments were (1) a weedy check, (2) a weed-free check created by hoeing and hand pulling weeds, (3) IR band-applied POST herbicides + hoeing between rows, (4) IR band-applied POST herbicides without BR weed control, and (5) IR band-applied POST herbicides + BR mowing twice (once when weeds were about 7.5 to 15.2 cm tall and again shortly before *G. max* canopy closure; Figure 3; Table 1). Weed-free *G. max* height and weed height at herbicide treatment or when first mowed are tabulated (Table 2).

Measurements

Crop stand was determined by counting plants in two 1.8-m lengths in each four-row plot (Table 1). Weed control in crop rows and between rows was evaluated visually at midseason and before harvest based on a scale of 0% (no control) to 100% (complete kill) (Table 1). *G. max* seeds were harvested with a small plot combine from the two center rows in each four-row plot in an area measuring 1.5 by 8.5 m (Table 1). After seed cleaning, yields and moisture contents were measured, and net yields were adjusted to 13% moisture.

Projected ground cover of grass and broadleaf weeds (percentage of the ground surface covered by vegetation (Bonham 1989) was measured from photographs taken either between crop rows or over rows above the *G. max* canopy about the same time weed control was visually rated (Table 1). Four photographs per plot were taken with either a video camera[5] or digital camera[6] at a height of 140 cm or 132 cm, respectively. Each photograph corresponded to 0.8 m^2 or 1.0 m^2, respectively, at the soil surface based on photographs of a 30- by 30-cm orange calibration plate. *G. max* foliage was pulled back with 1 m^2 black cloth-covered wooden frame panels for photographing BR weed cover. Weed canopy height was measured when each photograph was taken. Groundcover (percentage) of total, grass, and broadleaf weed cover was measured using image analysis

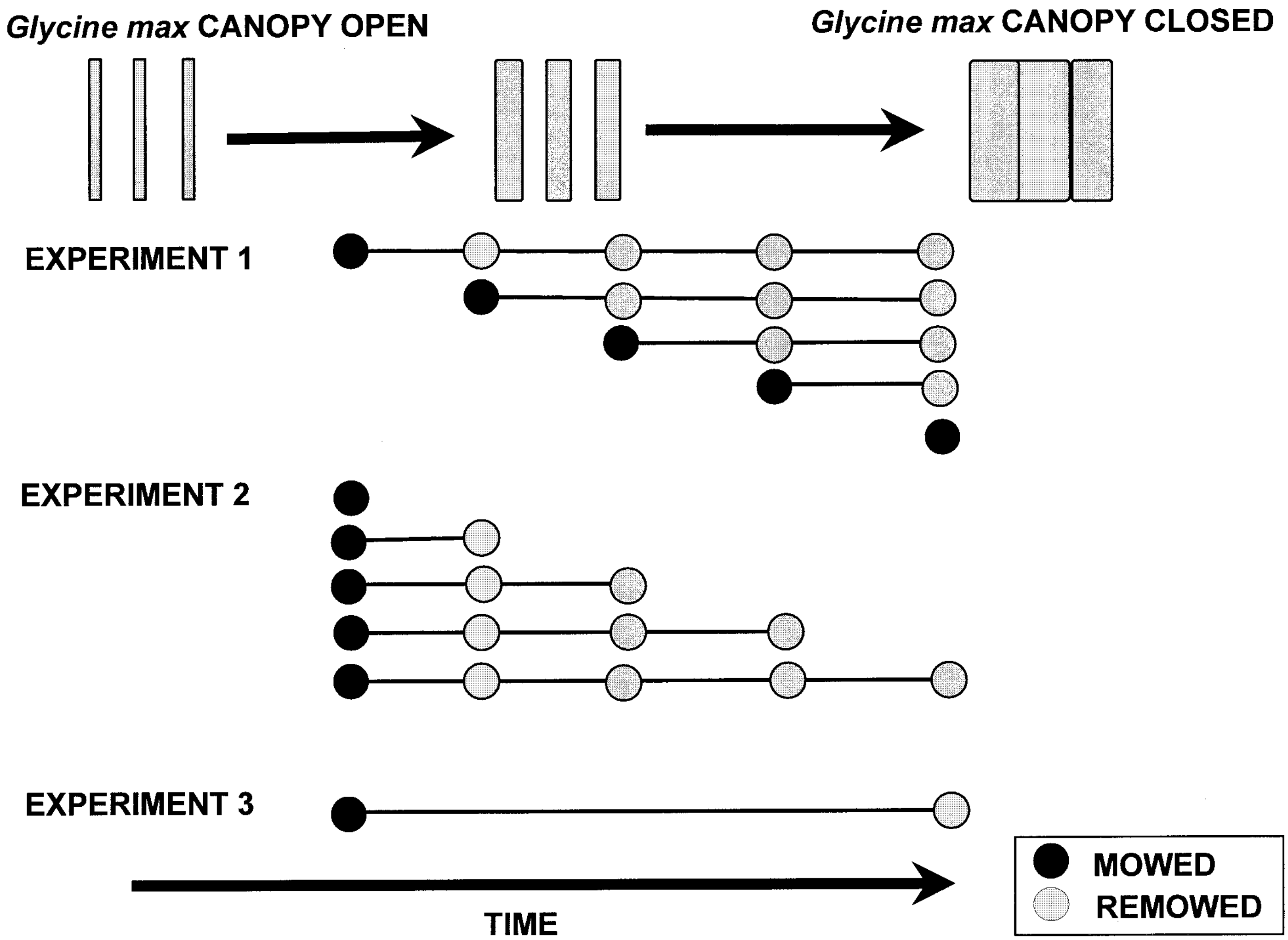

FIGURE 3. Schematic diagram showing how mowing and removing treatments were imposed over time in experiments 1 to 3 in relationship to *Glycine max* canopy closure.

software, and four measurements per plot were averaged separately for between-row and in-row regions of plots.

Experimental Design and Statistical Analysis

A randomized complete block experimental design was used with three blocks in 1993 (experiments 1 and 2) and four blocks in 1994 to 1998 (Hoshmand 1994; Petersen 1994). Blocking was based on slope position and weed infestation in previous years. Individual plots measured 3 m by 9.1 m for all experiments. Data were subjected to analysis of variance (ANOVA) using statistical software (SPSS 1998). Results are presented separately by year because treatment timing differed among years due to weather (Figure 2). Means were separated by Duncan's multiple range test at $P = 0.05$.

Results and Discussion

Experiment 1—Mowing Started at Different Times After Planting and Finished at the Same Time Before *G. max* Canopy Closure

G. max Yield

If BR-mowing weed management systems control weeds before they begin to interfere with crop yield component formation, then *G. max* yields in these systems should equal those in the hoed, weed-free check. Yields of the BR-mowing weed management systems should also be greater than the weedy check yield. Both predictions were confirmed for most BR-mowing weed management systems despite different weed-free yield potentials each year (Figure 5). If weeds were controlled only in crop rows with band-applied herbicides, then yields were reduced compared to the hoed, weed-free checks all 3 yr and could not be distinguished from the weedy check.

Both IR band-applied herbicides and BR mowing were required to prevent yield loss in *G. max* from weed interference (Figure 5). However, BR-mowing weed management systems that were mowed twice yielded as much as those that were mowed more often (i.e., three to five times per growing season). Because PRE + POST herbicides were band applied early after planting and controlled annual weeds well in crop rows, the first of these two BR mowings could be delayed until the weeds, chiefly *S. faberi*, were relatively tall (Figure 4). In 2 of 3 yr, the BR-mowing weed management system that was mowed only once per growing season, relatively late before *G. max* canopy closure, also yielded as well as the weed-free check plots (Figure 5). In this case, when IR band-applied PRE + POST herbicides

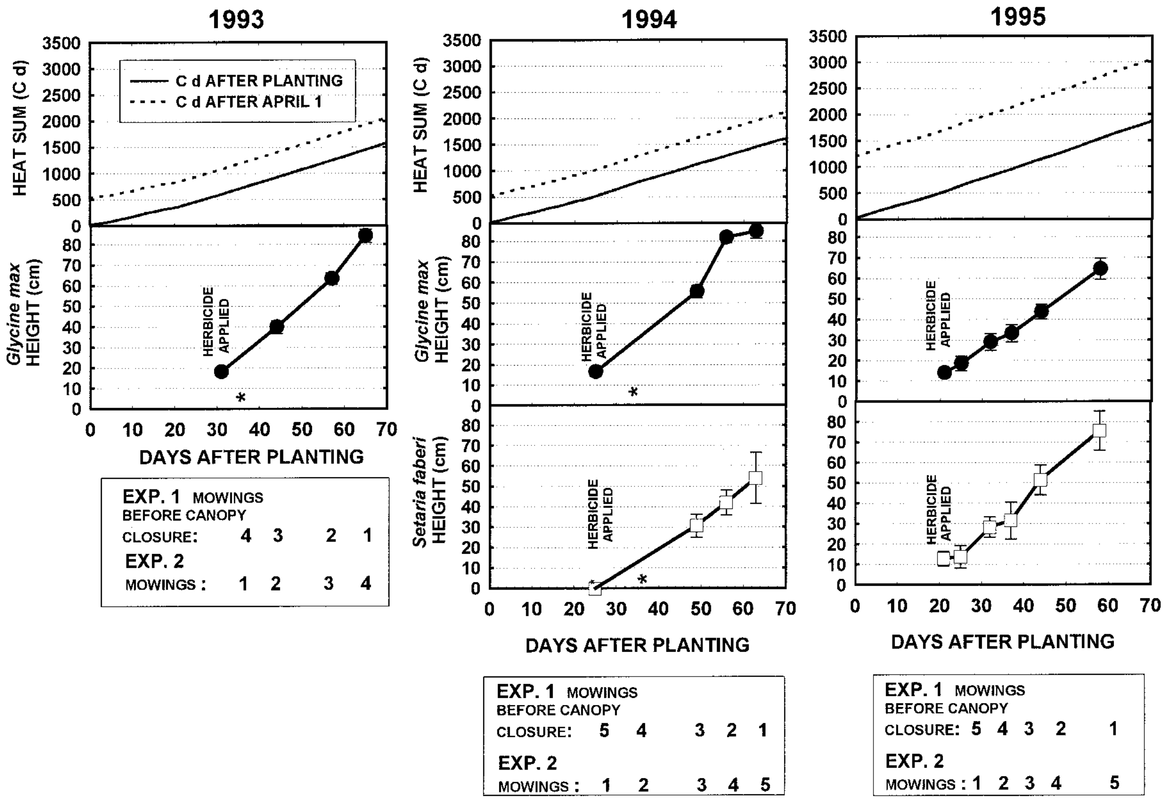

FIGURE 4. Weed-free *Glycine max* height and weed height (mean ± SD) at the time of mowing and/ or postemergence herbicide treatment graphed versus days after planting for experiments 1 and 2. Data not collected indicated by an asterisk.

adequately controlled weeds in crop rows, a single BR mowing could be made relatively late, when annual weeds were relatively tall, after most weed emergence. The data suggest that band-applied herbicides + two properly timed mowings per growing season might more consistently control annual weeds, without yield penalties, than only one mowing + IR band-applied herbicides.

Hoed, weed-free check yields differed from year to year and were ranked 1993 ≫ 1994 ≥ 1995 (Figure 5). This yield ranking probably reflects crop response to July and August rainfall (Figure 2). July rainfall during *G. max* seed formation was below average in 1994 and 1995, in sharp contrast to above-average July rainfall in 1993. In these studies all 3 yr, the efficacy of most BR-mowing weed management systems was independent of yield potential because yields of most BR-mowing weed management systems could not be distinguished from the weed-free check yields. The weedy checks yielded 79, 64, and 43% of weed-free checks in 1993, 1994, and 1995, respectively. These observations are consistent with reports that season-long weed interference reduced *G. max* yield most severely under moisture stress (Jackson et al. 1985; McWhorter 1991; Zollinger and Kells 1993).

Weed Cover

Competition experiments demonstrated that weeds growing in *G. max* rows can reduce yield more than those growing between rows (Beckett and Stoller 1988; Eaton et al. 1976; Henry and Bauman 1989, 1991; Mortensen and Coble 1989; Stoller and Woolley 1985; Thurlow and Buchanan 1972; Willard et al. 1994). Those weeds growing close to the crop likely begin to interfere with crop yield component formation earlier than those growing further away between crop rows. Thus, IR band-applied herbicide contributes to the success of BR-mowing weed management

TABLE 2. Weed heights at treatment in experiment 3 (mean ± standard deviation). Heat sums above a base temperature of 10 C were accumulated starting on April 1 each year.

Year	Treatment	Date	Heat sum	Height (cm)		
				S. faberi	*A. artemisifolia*	*Amaranthus* sp.
			C d	cm		
1996	Postherbicide	6/13/96	881	Not observed	Not observed	Not observed
	First mowing	6/27/96	1,224	17.7 (0.7)	13.0 (1.68)	16.9 (0.9)
1997	Postherbicide	6/30/97	1,269	8.5 (2.6)	13.0 (3.1)	—
	First mowing	6/27/97	1,169	9.0 (2.9)	9.5 (2.0)	—
1998	Postherbicide	6/26/98	1,413	8.9 (2.6)	7.9 (2.6)	—
	First mowing	6/23/98	1,328	8.2 (2.6)	6.5 (2.7)	—

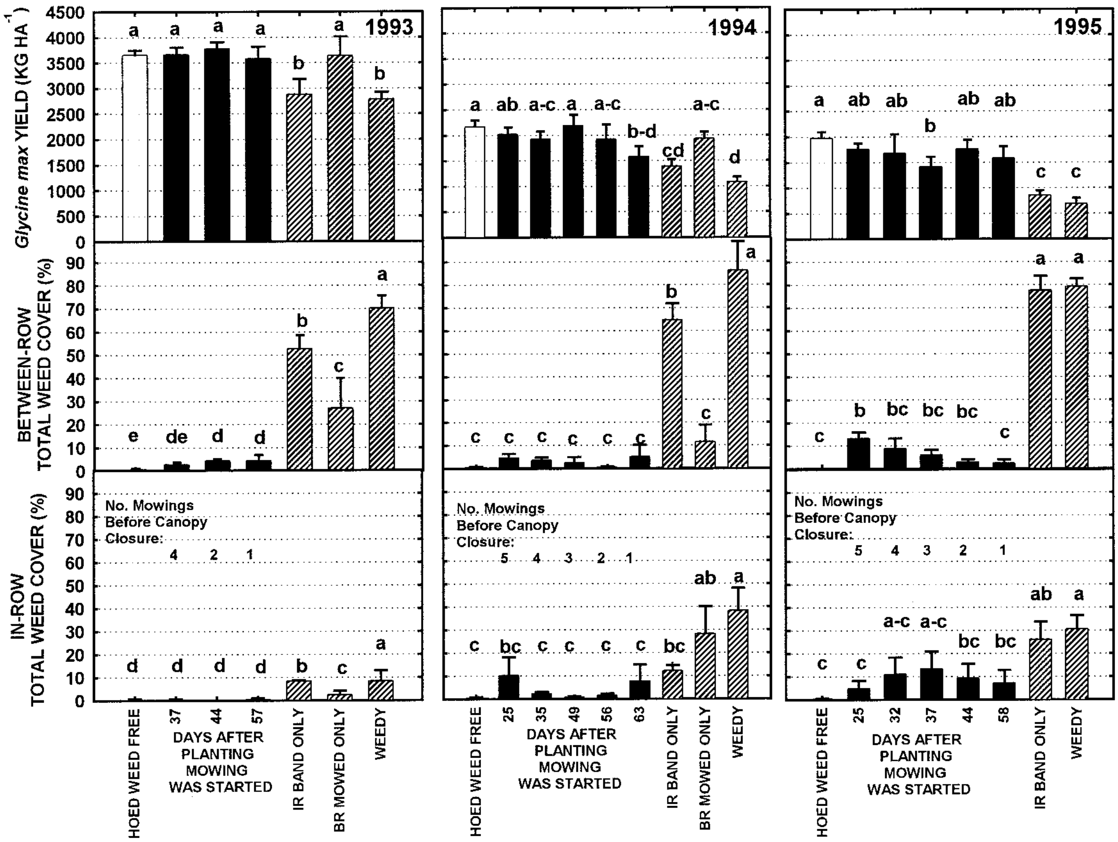

FIGURE 5. *Glycine max* yield, between-row (BR) total weed cover, and in-row (IR) total weed cover at midseason graphed versus treatment for experiment 1 from 1993 to 1995. Means ± standard errors are presented. Means for each variable in a year followed by the same letter were not different at P = 0.05 by Duncan's multiple range test.

systems by controlling weeds growing closest to crop rows early in the growing season, favoring early crop yield component formation (Figure 5).

Because all BR-mowing weed management systems were treated with IR band-applied herbicide, IR weed cover above the *G. max* canopy was expected to be minimal at midseason and comparable to the hoed, weed-free checks. This was observed all 3 yr (Figure 5). IR band-applied PRE metolachlor controlled *S. faberi* and suppressed *A. artemisiifolia* and *Amaranthus* sp. Surviving stunted annual broadleaf weeds and escapes were subsequently controlled by timely IR POST band-applied thifensulfuron. *S. faberi* accounted for most IR and BR weed cover in weedy checks (data not presented). Surprisingly, in 2 of 3 yr, midseason BR weed cover was lower in plots treated only with IR band-applied herbicide than in weedy check plots (Figure 5). Perhaps by controlling IR weeds IR band-applied herbicide treatment permitted earlier, more vigorous *G. max* canopy growth that suppressed BR weeds compared with the weedy checks.

IR and BR weed cover in weedy check plots was greater in 1994 and 1995 than in 1993 (Figure 5). Favorable moisture conditions in May and early summer of 1993 (Figure 2) may have encouraged early, complete *G. max* canopy closure that suppressed later weed cover development. In addition to delaying *G. max* canopy closure, below-normal rainfall after planting in May 1994 and June 1995 may have reduced the efficacy of IR PRE metolachlor and POST thifensulfuron, encouraging later heavier weed growth in crop rows. Shading by *G. max* canopies and interference for light reportedly suppressed weed growth, extended the duration of weed control (Rose et al. 1984; Stoller et al. 1987), and enhanced apparent herbicide efficacy (Kust and Smith 1969; Mickelson and Renner 1997; Weaver 1991). Shading the soil surface decreased weed seed germination and subsequent shoot growth (Fenner 1978).

Experiment 2—Mowing Started at the Same Time After Planting and Finished at Various Times Before *G. max* Canopy Closure

As in experiment 1, all BR-mowing weed management systems were treated with IR band-applied PRE and POST herbicide (Table 1). In experiment 2, mowing was started at the same time after planting for all BR-mowing weed management systems in a year, but mowing was ended at progressively later times after planting to create different BR-mowing weed management systems than in experiment 1 (Figure 3; Table 1).

G. max Yield

In 2 of 3 yr (1993 and 1995), several BR-mowing weed management systems increased yield above the weedy check (Figure 6). *G. max* yields were greater than the weedy checks for BR-mowing weed management systems, which were mowed three and four times in 1993 or five times in 1995. Apparently, when mowing was started early, yields were re-

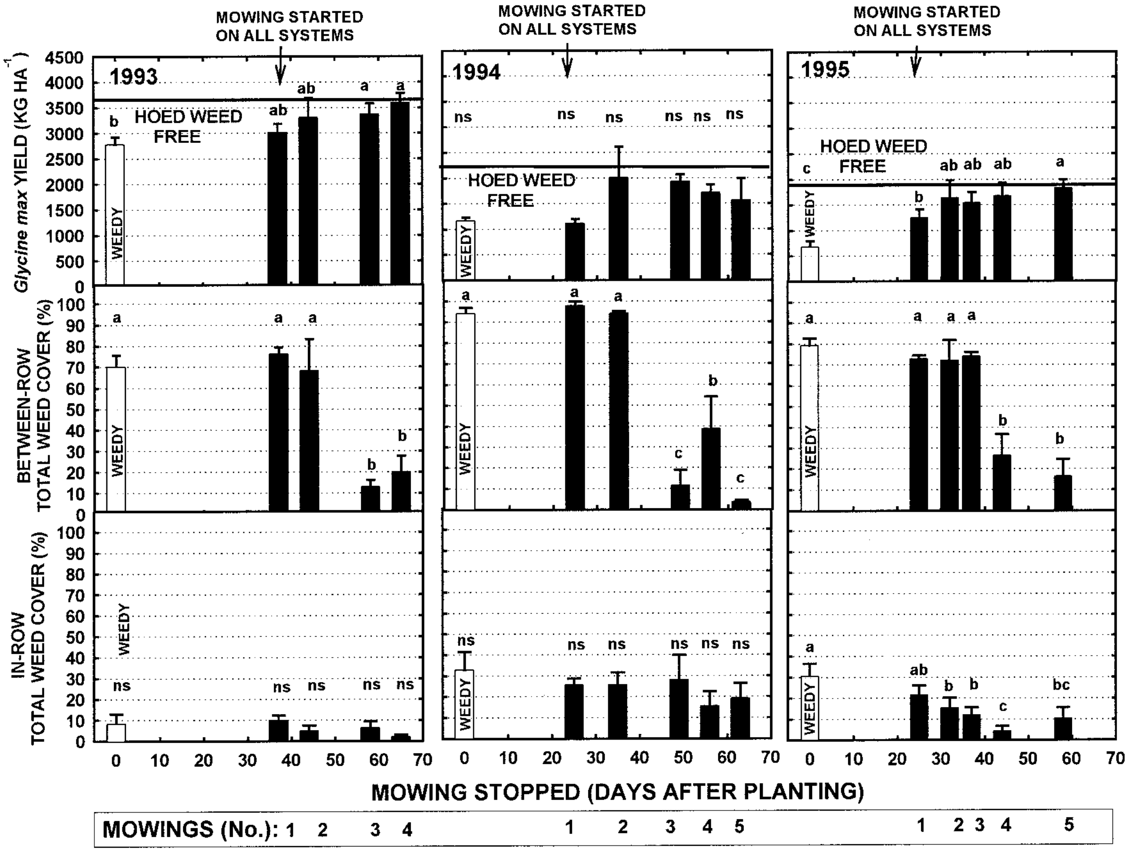

FIGURE 6. *Glycine max* yield, between-row (BR) total weed cover, and in-row (IR) total weed cover at midseason graphed versus days after planting for experiment 2 from 1993 to 1995. All mowings were started on the same day within a year for all BR-mowing weed management systems. Means ± standard errors are presented. Means for each variable in a year followed by the same letter were not different at P = 0.05 by Duncan's multiple range test.

duced if mowing was finished too soon before *G. max* canopy closure.

Unlike experiment 1, mowing once per growing season, early instead of late (Table 1; Figure 4), did not consistently control weeds and maintain yields comparable to the hoed, weed-free checks from year to year (Figure 6). Following a single mowing, *G. max* yields equaled the hoed, weed-free check in only 1 of 3 yr. In experiment 1, one properly timed mowing per growing season controlled weeds well enough that yields were comparable to the hoed, weed-free check in 2 of 3 yr (Figure 5). Mowing once was performed early when weeds were small and the *G. max* canopy was still quite open in experiment 2, whereas mowing once was performed late when weeds were taller just before *G. max* canopy closure in experiment 1 (Figures 3 and 4).

Weed Cover

When measured midseason after all treatments were imposed, total BR weed cover was indistinguishable from the weedy check (> 65%) for those BR-mowing weed management systems in which mowing was ended 25 to 37 d after planting (DAP), even though these BR-mowing weed management systems received at least two mowings (Figure 6). Relatively greater IR and BR weed cover for these latter BR-mowing weed management systems likely explain low *G. max* yields. By midseason, BR weeds that were mowed once or twice had enough time without crop shading to regrow to cover the ground as much as in the untreated, weedy checks even though mowed weeds formed a stunted "carpet" on the soil. BR weed cover, chiefly *S. faberi,* was decreased well below the weedy check with four or more mowings per growing season in experiment 2 (Figure 6). Reportedly, control of annual grass weeds, other than *S. faberi,* increased as mowing height was decreased and mowing frequency was increased (Aiken et al. 1995; Vengris et al. 1966), although weeds were not mowed as close as 2.5 cm above the soil surface in these reports.

Mowing once soon after planting (25 to 37 DAP) in experiment 2 did not greatly reduce subsequent BR weed regrowth or weed cover from newly emerged weeds in contrast to mowing once later (58 to 65 DAP) in experiment 1 after most annual weeds had emerged and weed cover was nearly finished (Figure 6). In these two experiments, light and temperature conditions at the soil surface were likely different after a single mowing. Because *G. max* canopy closure shaded the soil surface and changed light intensity and quality, canopy closure soon after mowing in experiment 1 suppressed weed regrowth from tiller buds following mowing and kept surviving weeds small, stressed, and noncompetitive. *G. max* shading combined with higher temperatures in mid- to late summer after major flushes of weed emergence also likely suppressed later weed emergence by inducing secondary dormancy in summer annual weed seed (Allen and Meyer 1998; Thompson 1987).

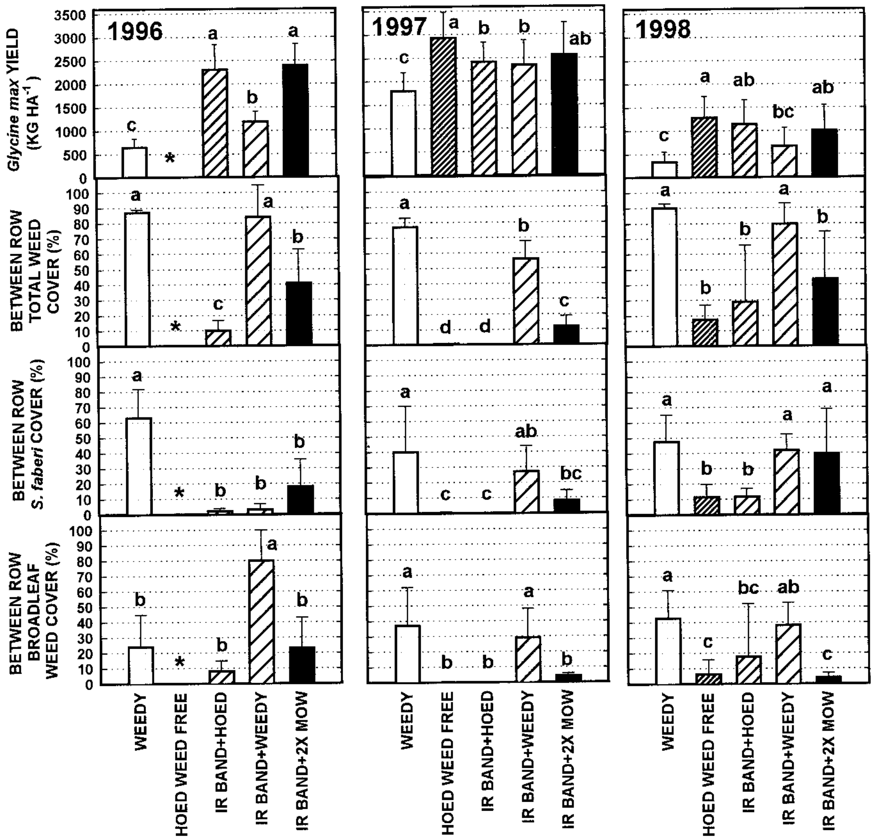

FIGURE 7. *Glycine max* yield, between-row (BR) total, *Setaria faberi*, and annual broadleaf weed cover at midseason graphed versus treatment for experiment 3 from 1996 to 1998. Means ± standard errors are presented. Means for each variable followed by the same letter were not different at P = 0.05 by Duncan's multiple range test. Data not collected indicated by an asterisk.

Experiment 3—BR-Mowing (2×) Weed Management System

G. max Yield

The BR-mowing (2×) weed management system increased yields over the weedy check in all 3 yr (Figure 7). Yield of the BR-mowing (2×) weed management system also could not be distinguished from the hoed, weed-free check in 1997 and 1998 (this check was omitted in 1996) or the IR band-applied herbicide + BR hoed treatment in all 3 yr.

The BR-mowing (2×) weed management system yielded more than the IR band-applied POST herbicide alone (i.e., weedy between rows) in only 1 of 3 yr, 1996, but was indistinguishable from it in 1997 and 1998 (Figure 7). Nevertheless, while the hoed, weed-free check was indistinguishable from the BR-mowing (2×) weed management system, the weed-free check was greater than the band-applied herbicide alone in all 3 yr. It is puzzling why the BR-mowing (2×) weed management system was greater than the IR band-applied herbicide (weedy between rows) in only 1 of 3 yr in experiment 3. Perhaps, given the variability in the yield data in the relatively dry years 1996 to 1998, greater statistical power from more blocking may be needed to distinguish small yield differences between treatments. Alternatively, IR band-applied PRE + POST herbicide treatments may perform more consistently and yield more than entirely IR band-applied POST herbicide treatments in the BR-mowing (2×) weed management system. Additional research is required to distinguish between these possibilities.

Weed Cover

The BR-mowing (2×) weed management system reduced BR total weed cover below the weedy check in all 3 yr (Figure 7). In 2 of 3 yr, hoed, weed-free treatments reduced midseason BR total weed cover more than did the BR-mowing (2×) weed management system (Figure 7). In the third year, 1998, differences could not be distinguished between these treatments. In 1998, the *G. max* canopy failed to completely close because of dry conditions (Figure 2). Even though the total weed cover was greater in 1998 for these treatments than in the previous 2 yr because of incomplete *G. max* canopy closure, the BR total weed cover was severely stunted following either two mowings or hoeing and hand weeding and formed a "carpet" (personal observation).

In 1998, incomplete *G. max* canopy closure allowed greater light intensities to reach the soil surface later during the growing season. Apparently, environmental factors that prevent early, rapid *G. max* canopy closure and soil surface shading encouraged some regrowth of mowed weeds. Crop management practices that encourage early, rapid *G. max* canopy closure and shading, such as narrow *G. max* row spacing, may suppress weed recovery following mowing, as observed for other weed management systems (Stoller et al. 1987). Without crop shading, *S. faberi* readily regrew from tillers to set seed following repeated cutting 5.1 cm above

TABLE 3. Characteristics of the between-row-mowing weed management system compared to either broadcast herbicide treatment or band herbicide + cultivation for row crops, such as *G. max.*

Category	Criteria	Weed control method: Broadcast herbicide	Band herbicide	Between-row-mowing	Field cultivation
Offsite environmental effects	Can be legally used near environmentally sensitive areas, such as water	Herbicide dependent	Herbicide dependent	Yes	Yes
	Herbicide drift is possible	Yes	Yes	No	No
	Causes air contamination	Herbicide residues	Herbicide residues	Dust	Dust
	Causes soil compaction	Soil-type and moisture dependent	Soil-type and moisture dependent	Soil-type and moisture dependent	Yes, soil type dependent
	Causes soil erosion	No	No	No	Yes
	Sediment in runoff reduces water quality	No	No	No	Yes
	Herbicides in runoff contaminates water and reduces water quality	Yes	Yes	No	No
	Herbicide amount/acre relative to broadcast herbicide application	1 ×	0.5–0.6 ×	0	0
	May harm beneficial insects/wildlife/fish	Directly, herbicide dependent	Directly, herbicide dependent	No	Indirectly, by sediment in runoff
	Public (nonuser) perceives negative environmental effect of this weed control method	Yes	Yes	No	No
User health hazards	Nature of health hazards	Herbicide	Herbicide	Dust, allergens	Dust, allergens
	Pesticide certification required	Yes	Yes	No	No
	Specific safety clothing/equipment required	Yes, herbicide dependent	Yes, herbicide dependent	No	No
Direct effects on crop quality	Pesticide residues in crop may limit potential consumer acceptance	Yes, herbicide and rate dependent	Yes, herbicide and rate dependent	No	No
	Pesticide residues in crop may limit export markets	Yes, herbicide and rate dependent	Yes, herbicide and rate dependent	No	No
	Herbicide-resistant GMO (genetically modified organisms) crops may limit export markets	Yes, crop dependent	Yes, crop dependent	Crop dependent	Crop dependent
Public health hazards	Public believes method is a health hazard	Yes	Yes	No	No
Weed control characteristics	Mechanical method	No	No	Yes	Yes
	Chemical method	Yes	Yes	No	No
	Preventative weed control strategy (before weed emergence)	Herbicide and rate dependent	Herbicide and rate dependent	No	No

Table 3. Continued.

Category	Criteria	Weed control method: Broadcast herbicide	Band herbicide	Between-row-mowing	Field cultivation
	Therapeutic weed control strategy (after weed emergence)	Herbicide and rate dependent	Herbicide and rate dependent	Yes	Yes
	Can be used in crop rows	Yes, banding over crop rows	Yes, banding over crop row	No	No
	Can be used between rows	Yes	Yes, but banding is usually over crop rows	Yes	Yes
	Many annual broadleaf and grass weeds are controlled	Herbicide and rate dependent	Herbicide and rate dependent	Yes	Yes
	Weed control efficacy (%)	~90–100	~80–100	~90–100	~50–80
	Weed control efficacy depends on weed density	Herbicide and rate dependent	Herbicide and rate dependent	No	Yes
	Weed control method must be timed before weeds become too large to control	Herbicide and rate dependent	Herbicide and rate dependent	Yes	Yes
	Weed control efficacy decreases when time after weed size threshold reached	Herbicide and rate dependent	Herbicide and rate dependent	No	Yes
	Many weed growth stages can be controlled	Herbicide and rate dependent	Herbicide and rate dependent	Yes	No
	Weed control efficacy is reduced by drought	Yes	Yes	No	No
	Weed control efficacy is reduced by moist soil conditions	No	No	No	Yes
	Weed control efficacy is reduced by high temperature	Yes	Yes	No	No
	Weed control lasts for growing season	Herbicide, rate, and environment dependent	Herbicide, rate, and environment dependent	No	No
	Weed control is consistent and predictable year to year	Herbicide, rate, and environment dependent	Herbicide, rate, and environment dependent	Yes	Timing dependent
	Wind limits treatment	Yes	Yes	No	No
	Soil moisture limits treatment timing due to soil trafficability	Yes	Yes	Yes	Yes, soil must be dry enough to work
	Weed resistance to control method has been reported	Weed, rate, and herbicide dependent	Weed, rate, and herbicide dependent	No	Yes, species dependent
	Controls herbicide-resistant weeds	Weed, herbicide, and rate dependent	Weed, herbicide, and rate dependent	Yes	Yes
	Crop selectivity	Herbicide and rate dependent	Herbicide and rate dependent	Positional, between crop rows	Positional, between crop rows

TABLE 3. Continued.

Category	Criteria	Weed control method: Broadcast herbicide	Band herbicide	Between-row-mowing	Field cultivation
	Crop damage	Herbicide, rate, and environment dependent	Herbicide, rate, and environment dependent	No, if properly used	No, if properly used
	Crop variety damage	Herbicide, rate, and environment dependent	Herbicide, rate, and environment dependent	No	No
	Weed control method can be safety used over many crop growth stages before canopy closure	Crop and herbicide dependent	Crop and herbicide dependent	Yes	Yes
Adaptability	Adapted to diverse tillage systems, including no-till	Yes	Yes	Yes	No
	Adapted to organic farming	No	No	Yes	Yes
	Adapted to many row crops	Herbicide and crop dependent	Herbicide and crop dependent	Yes	Yes
	Adapted to diverse farm scales	Yes	Yes	Yes	Yes
On-site environmental effects	Herbicide residue can carryover or persist to damage rotational crops	Herbicide, rate, and environment dependent	Herbicide, rate, and environment dependent	No	No
	Treated crop residue can be grazed	Herbicide dependent	Herbicide dependent	Yes	Yes
Weed control costs	Weed scouting cost per trip (Plain et al. 1998)	$0.81 to 2.02 [($0.81)/ha] [$2 to 5 ($2)/acre]	$0.81 to 2.02 [($0.81)/ha] [$2 to 5 ($2)/acre]	$0.81 to 2.02 [($0.81)/ha] [$2 to 5 ($2)/acre]	$0.81 to 2.02 [($0.81)/ha] [$2 to 5 ($2)/acre]
	Equipment costs	Herbicide sprayer	Herbicide sprayer	Between row mower	Field cultivator
	New purchase ($) (Lazarus 1998)	$4,140 to 21,960	$4,140 to 21,960	Unknown	$3,330 to 18,810
	Operating expense ($/acre) (Lazarus 1998)	$0.13 to 0.25/ha [$0.31 to 0.62/acre]	$0.13 to 0.25/ha [$0.31 to 0.62/acre]	Unknown	$0.33 to 0.49/ha [$0.81 to 1.22/acre]
	Diesel fuel (Lazarus 1998)	1 to 2 L/ha [0.14 to 0.21 gal/acre]	1 to 2 L/ha [0.14 to 0.21 gal/acre]	Unknown	5 to 7.5 L/ha [0.55 to 0.82 gal/acre]
	No. trips/acre	1 to 2	1 to 2	1 to 2	1 to 2
	Implement width (Lazarus 1998)	12.2 m [40 ft]	12.2 m [40 ft]	~3.0 to 6.1 m [~10 to 20 ft]	3.7 to 12.2 m [12 to 40 ft]
	Operating speed (Lazarus 1998)	6.5 km/h [4 mi/h]	6.5 km/h [4 mi/h]	Unknown	6.5 km/h [4 mi/h]
	Area/h (Lazarus 1998)	5.1 ha/h [12.6 acre/h]	5.1 ha/h [12.6 acre/h]	Unknown	2.1 to 5.7 ha/h [5.2 to 14.0 acres/h]
	Custom rate range (average) (Plain et al. 1998)	$1.21 to 6.07 ($1.62)/ha [$3 to 15 ($4)/acre]	$1.21 to 6.07 ($1.62)/ha [$3 to 15 ($4)/acre]	Unknown	$1.62 to 6.07 (2.83)/ha [$4 to 15 ($7)/acre]
	Herbicide cost range (Plain et al. 1998)	$0.89 to 11.94/ha [$2.2 to 29.50/acre]	$0.45 to 5.96/ha [$1.1 to 14.75/acre]	0	0
	Pesticide record-keeping cost	Yes	Yes	No	No
	Pesticide notification cost	Yes	Yes	No	No

the soil surface at several growth stages (46 to 154 cm tall) (Schreiber 1965). However, the cutting height used by Schreiber (1965) was about twice that used in this research. Mowing height, mowing timing, weed growth stage, and crop shading contribute to successful weed management in the BR-mowing (2×) weed management system.

The characteristics of BR mowing are compared with field cultivation, band-applied herbicide, and broadcast-applied herbicide (Table 3). As noted, the BR-mowing (2×) weed management system consisted of BR mowing + IR band-applied herbicide. Most farmers who use field cultivation also band apply herbicides. Because BR-mowing weed management systems leave a stunted carpet of weeds and crop residue between crop rows to protect the soil surface, this weed management system will likely reduce the chance of soil erosion during the critical 30- to 45-d period after planting, when exposed soil is most prone to erosion (Renard et al. 1994). Others noted the contribution of weed cover to preventing soil erosion, but usually only after harvest or before planting (Dabney 1998; Pannkuk et al. 1997; Zhu et al. 1989). While the BR-mowing (2×) weed management system reduced herbicide use by 50% in this research, reductions up to 60% are possible and are proportional to the land area that is sprayed. Properly timed, reduced-rate herbicide treatments may further decrease herbicide use. Because the BR-mowing weed management system reduced herbicide use without disturbing the soil surface, it would likely minimized potential water contamination by herbicides and sediment in runoff. Published research documented that banding reduced herbicide loss in runoff water (Baker and Johnson 1983; Gaynor and Van Wesenbeeck 1995; Gaynor et al. 1995). Furthermore, the BR-mowing weed management system has potential for use in no-tillage farming systems.

Sources of Materials

[1] 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.

[2] DR Trimmer/mower 5.0 HP 2-cycle, "XL" Pro, Country Home Products, Ferry Rd., Box 89, Charlotte, VT 05445.

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

[4] Teejet flat fan even spray nozzle SS 8501 EVS, Spraying Systems Co., Wheaton, IL 60187.

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

[6] Olympus D-600 L digital camera, Olympus America Inc., Two Corporate Center Drive, Melville, NY 11747-3157.

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