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Timing and Frequency of Between-Row Mowing and Band-Applied Herbicide for Annual Weed Control in Soybean

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ABSTRACT

Alternative ways are needed to control weeds in field crops that reduce or prevent both herbicide contamination of surface and ground water and soil erosion. A new weed management system, which consisted of band-applied herbicides over the soybean [*Glycine max* (L.) Merr., 'Morsoy 9137'] row and two or more between-row (BR) mowings, was optimized in a soybean field near Columbia, MO. Between-row mowing very close to the soil surface twice with a mower killed or suppressed annual grass and broadleaf weeds, chiefly giant foxtail (*Setaria faberi* R. Herrm.), common ragweed (*Ambrosia artemisiifolia* L.), and waterhemp species (*Amaranthus* spp.), when properly timed. When band-applied herbicide controlled weeds within the crop row, annual weeds between rows could be mowed once when the tallest weeds were 8 to 24 cm tall and again just before crop canopy closure, without yield loss. No more than two BR mowings were needed to control annual weeds. Shading by crop canopy closure contributed to weed suppression in this BR-mowing weed management system. Soybean yield in the BR-mowing weed management system could not be statistically distinguished from hoed, weed-free check plots or broadcast-herbicide treatments 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 BR-mowing weed management system may have use in environmentally sensitive areas to help reduce soil erosion and/or water contamination by herbicides.

THERE is a national need to find profitable, weed management systems that help farmers reduce both soil erosion and surface water contamination by sediment, nutrients, and herbicides, without greatly changing current farming practices (i.e., without reducing yields or increasing costs). Most farmers now rely on herbicides and, to a lesser extent, cultivation for controlling weeds in corn (*Zea mays* L.) and soybean in the Midwest (Anonymous, 1999). If unanticipated, unpredictable, and negative environmental effects of current weed management practices (Brock, 1982; Daniel et al., 1998; Logan et al., 1987; Mutchler and Greer, 1984; Pelly, 1998; Richards and Baker, 1993) are to be minimized, then both cultivation and herbicide use must be reduced (Logan, 1993; Logan et al., 1987).

Band-applying herbicides over crop rows and substituting BR mowing for cultivation to control weeds between rows is an alternative weed management system in competitive row crops, such as soybean (Donald, 2000a). Although one BR mowing per growing season did not consistently control weeds from year to year, two or more BR mowings consistently controlled weeds in this BR-mowing weed management system (Donald, 2000b). It is not known, however, how to best time BR mowing to most effectively or flexibly control weeds and reduce weed competition in soybean. Neither the optimum timing between starting and stopping BR mowing nor the optimum frequency of mowing (two or three mowings per growing season) are known. Knowledge of how to best time BR mowing to optimize weed control would allow greater flexibility in using the BR-mowing weed management system.

Management decisions concerning when and how frequently to mow weeds between rows will likely depend upon weed species and density, as well as the relative times of emergence and relative growth rates of weeds compared with the crop. Crop management practices that stimulate early crop canopy closure, such as narrow row spacing, fertilization for optimum yield, or early planting, may affect the number and timing of BR mowings required for acceptable weed control. Crop canopy closure will likely limit the window of opportunity for BR mowing because vehicle traffic will likely damage the crop after canopy closure. In addition, weed-induced yield losses sustained before crop canopy closure make later weed control efforts less effective in reducing losses due to weed interference (Stoller et al., 1987; Zimdahl, 1980, p. 83–93).

The goal of this research on the BR-mowing weed management system was to determine the relative effectiveness of various start and stop times and frequencies of mowing on weed control and soybean yield.

MATERIALS AND METHODS

Treatments

Various BR-mowing weed management systems were compared with a weedy check, a hoed, weed-free check, and broadcast-applied herbicide. Between-row-mowing weed management systems consisted of (i) a competitive crop (soybean), (ii) band-applied herbicide over crop rows, and (iii) BR mowing. Between-row mowings were started at three progressively greater weed heights (small, medium, and large) and included two frequencies of mowing, either two or three times per season before canopy closure (Tables 1–3). Previous research demonstrated that one BR mowing per growing season and in-row (IR) band-applied herbicide did not consistently control weeds between rows (Donald, 2000b). The last of two or three mowings was imposed just before soybean canopy closure for both frequencies of mowing.

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Abbreviations: BR, between row; IR, in row.

Table 1. Dates of field operations and measurements.

Field operation or measurement	1997	1998
Fertilize with phosphorous and potassium	8 May	14 May
Disk harrow for spring seedbed preparation and fertilizer incorporation	13 May	14 May
Plant soybean	14 May	29 May
Soybean emergence first observed	27 May	7 June
Apply postemergence thifensulfuron + quizalofop	30 June	–
Apply postemergence aciflourfen + sethoxydim	–	26 June
Mow weeds (weeds "small")	27 June	23 June
Mow weeds (weeds "medium")	2 July	29 June
Mow weeds (weeds "large")	7 July	9 July
Mow weed regrowth (second of three mowings)	15 July	22 July
Final mowing (second of two or third of three mowings)	22 July	30 July
Hand-pull and hoe weeds in check plots	2 July	22 June
	10 July	1 July
	23 July	14 July
	29 July	30 July
Photograph weed ground cover	30 July	11 Aug.
Visually rate weed control	1 Aug.	7 Aug.
	29 Sept.	13 Oct.
Harvest soybean	3 Oct.	16 Oct.

A randomized complete block experimental design was used with nine treatments (Tables 2 and 3) and either four blocks in 1997 or five blocks in 1998, depending upon available land (Hoshmand, 1994). Blocking was based on slope position and weed ground cover observed in previous years. Individual plots measured 3 by 9.1 m.

Between-Row Mowing

Between-row weeds were controlled by close mowing with a XL PRO model DR trimmer/mower (Country Home Products, Charlotte, VT)[1] operated about 2.5 to 3 cm above the soil surface (Tables 1 and 2). The BR mowing width was 60 cm, leaving about 7.6 cm unmowed next to each side of 76-cm-wide crop rows. For the 2× BR mowing treatments, BR mowing was first imposed when weeds were about 8 to 9 cm tall and was repeated shortly before soybean canopy closure. For the 3× BR mowing treatments, BR mowing was first imposed at the same weed heights as the 2× BR mowing. Then, the weed regrowth was removed again when it was about 7.6 to 15.2 cm tall followed by a third BR mowing, shortly before soybean canopy closure. The dates and heights of hoed, weed-free soybean and the major weeds at postemergence herbicide treatment or at the first BR mowing are shown in Table 3.

[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.

In-Row Banded Herbicide Treatment

Postemergence thifensulfuron {3-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]-2-thiophenecarboxylic acid} at 0.0175 kg a.i. ha^{-1}, quizalofop {(±)-2-[4-[(6-chloro-2-quinoxalinyl)oxy] phenoxy]propanoic acid} at 0.56 kg a.i. ha^{-1}, and nonionic surfactant at 0.125% (by volume) were band-applied for annual and broadleaf weed control (Table 2). 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. Because sulfonylurea-herbicide resistant common ragweed (AMBEL[2]) and waterhemp species were suspected in 1997, herbicides were changed in 1998 to aciflourfen {5-[2-chloro-4-(trifluoromethyl) phenoxy]-2-nitrobenzoic acid} at 0.56 kg a.i. ha^{-1}, sethoxydim {2-[1-(ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one} at 0.43 kg a.i. ha^{-1}, and crop oil concentrate at 2.3 L ha^{-1} (Table 1). Herbicides were sprayed in 38-cm-wide bands over crop rows with a backpack sprayer operated at 4.5 km h^{-1} using compressed CO_2 at 207 kPa in a spray volume of 110 L ha^{-1} water with flat fan nozzles (Teejet even spray nozzle SS 8501 EVS, Spraying Systems Co., Wheaton, IL).

Agronomic Practices

The experiment was conducted in 1997 and 1998 at the University of Missouri's Bradford Experimental Farm near Columbia (38°53′43.5″ N, 92°12′37.9″ W, 883 m altitude). The soil was a Mexico silt loam (fine, smectitic, mesic Aeric Vertic Epiaqualf) with 18 to 20% sand, 46 to 48% silt, 34% clay, 2.7 to 3.3% organic matter, and a pH of 5.3 to 5.8. Field operation dates for treatments and measurements are summarized in Table 1.

The experiment was repeated on an adjacent site in a corn–soybean rotation that was started in 1992. Soybean fertilization was based on soil tests and recommendations of the University of Missouri soil testing lab. Fertilizer containing P_2O_5 and K_20 was broadcast before planting at 73 and 90 kg ha^{-1} in 1997 and 84 and 84 kg ha^{-1} in 1998 for a weed-free yield goal of 2690 kg ha^{-1}. Fertilizer was incorporated by disc-harrowing and/or cultipacking for seedbed preparation. 'Morsoy 9137' soybean seed was planted in 76-cm rows 1.3 to 1.9 cm deep

[2] Letters following plant names are five letter computer codes of the Weed Science Society of America's publication *Composite List of Weeds.*

Table 2. Treatments

		BR weed control treatment†		
No.	IR weed control treatment†	BR treatment	Number before canopy closure	Weed size when first mowed or sprayed‡
1	none, weedy check		–	–
2	hoed, weed-free check		–	small
3	IR band-applied herbicide +	BR mowed	2 X	small
4	IR band-applied herbicide +	BR mowed	3 X	small
5	IR band-applied herbicide +	BR mowed	2 X	medium
6	IR band-applied herbicide +	BR mowed	3 X	medium
7	IR band-applied herbicide +	BR mowed	2 X	large
8	IR band-applied herbicide +	BR mowed	3 X	large
9	Broadcast-applied herbicide		NA	small

† IR, in row; BR, between row.
‡ Weed height at the time of first mowing or herbicide spraying is summarized in Table 3.

with a four-row planter at 389 000 and 340 000 seeds ha^{-1} in 1997 and 1998, respectively. Weather data were collected at the Bradford Experimental Farm (Fig. 1).

Hoed, Weed-Free and Weedy Check Plots

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

Weeds Present

Giant foxtail (SETFA) was the predominant annual weed present and often accounted for most weed ground cover. Common ragweed (AMBEL) and waterhemp species were the most common and dense annual broadleaf weeds present. Common cocklebur (*Xanthium strumarium* L. XANST), common lambsquarters (*Chenopodium album* L. CHEAL), giant ragweed (*Ambrosia trifida* L. AMBTR), ladysthumb smartweed (*Polygonum persicaria* L. POLPE), Pennsylvania smartweed (*Polygonum pensylvanicum* L. POLPY), velvetleaf (*Abutilon theophrasti* Medik. ABUTH), and yellow nutsedge (*Cyperus esculentus* L. CYPES) were sparse.

Measurements

Crop stand was determined by counting plants in two 1.8-m lengths in each four-row plot (Table 1). Weed control in 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). Soybean seed was harvested with a plot combine from the two center rows 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 (%) of the ground surface covered by vegetation (Bonham, 1989, p. 96–135) was measured from photographs taken either between crop rows or over rows above the soybean canopy about the same time weed control was visually rated (Table 1). Four photographs per plot were taken with either a video camera (RC-570 still video camera, Cannon U.S.A., Lake Success, NY) or digital camera (Olympus D-600 L digital camera, Olympus America, Melville, NY) at a height of 140 cm or 132 cm in 1997 and 1998, 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. Weed height was measured when each photograph was taken. Soybean foliage was pulled back with 1-m^2 black cloth-covered wooden frame panels for photographing BR weed

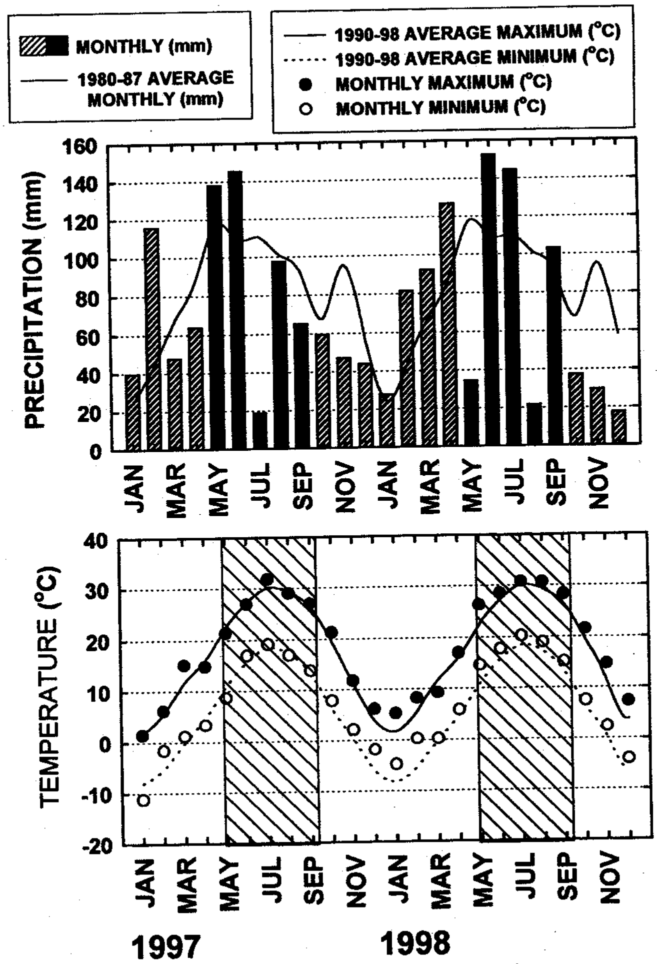

Fig. 1. Monthly precipitation and maximum and minimum temperature, as well as long-term (1980–1998) average monthly precipitation and maximum and minimum temperature graphed versus time. The growing season, which extended from May to September, is indicated by black bars or hatched shading.

cover. Video photographs were digitized (SV-PC SV Digitzer still video board, Cannon) in 1997 and saved as TARGA files for image analysis (Sigma Scan Prov v. 1 and 2, Jandel Scientific, San Rafael, CA). Digital photographs were saved as JPEG files in 1998. Projected ground cover of total, grass, and broadleaf weed foliage was measured manually in pixels and was expressed as a percent of all pixels per photograph. Ground cover (%) of total, grass, and broadleaf weed cover was measured using image analysis software and four measurements per plot were averaged separately for BR and IR regions of plots. Between-row weed cover index (WCI) was used to

Table 3. Soybean and weed height when first mowed or treated with herbicide.

Year	Treatment	Date	Soybean height	Weed height at treatment† Giant foxtail	Common ragweed	Waterhemp sp.
			cm			
1997	herbicide	30 June	33.5 (3.2)	8.5 (2.6)	13.0 (3.1)	–
	mowing ("small")	27 June	22.2 (4.2)	9.0 (2.9)	9.5 (2.0)	–
	mowing ("medium")	2 July	36.6 (6.0)	24.8 (6.7)	16.3 (4.0)	14.1 (3.7)
	mowing ("large")	7 July	39.7 (3.9)	31.5 (7.3)	20.1 (5.2)	20.7 (3.4)
1998	herbicide	26 June	16.1 (1.7)	8.9 (2.6)	7.9 (2.6)	–
	mowing ("small")	23 June	15.8 (1.6)	8.2 (2.6)	6.5 (2.7)	–
	mowing ("medium")	29 June	25.6 (2.0)	24.4 (6.7)	21.7 (6.1)	20.8 (5.2)
	mowing ("large")	9 July	38.5 (3.1)	30.6 (6.6)	26.8 (5.5)	24.5 (7.9)

† Means (± standard deviations) are presented.

weight BR weed cover by weed height normalized to the tallest weed present within a year and was calculated as follows:

$$\mathrm{WCI} = \mathrm{WC} \times (H/H_{max}) \qquad [1]$$

where WCI = BR weed cover index, WC = BR weed cover (%), H = BR weed height (cm), and H_{max} = BR maximum weed height (cm).

Statistical Analysis

Data were subjected to ANOVA using SPSS statistical software (Hoshmand, 1994; SPSS, 1998). Means were separated by Duncan's multiple range test at $P = 0.05$ (Hoshmand, 1994). Soybean yield was subjected to regression analysis versus IR or BR total weed cover by year, as well as multiple regression analysis versus both independent variables by year (Hoshmand, 1994).

RESULTS AND DISCUSSION

Soybean Yield

It was expected that soybean yields of most BR-mowing weed management systems would be greater than the weedy check, but no different than the hoed, weed-free check or the broadcast herbicide treatments. This was observed for all BR-mowing weed management systems, with one exception (Fig. 2). The only exception was that the yield of the hoed, weed-free check was greater than that of the IR + 3× BR-mowing weed management system in which BR mowing was started when weeds were largest. The yields of all BR-mowing weed management systems and the broadcast herbicide were greater than the weedy check, as expected. The BR-mowing weed management systems that received either two or three BR mowings started at the same growth stage could not be distinguished from one another. There was no yield advantage to BR mowing three times compared with BR mowing twice. As the first BR mowing was delayed until weeds became larger, yields tended to decrease, but yields of all BR-mowing weed management systems could not be distinguished statistically from one another. Thus, when weeds were controlled with band-applied herbicides over crop rows, the window of opportunity for starting BR mowing in this weed management system was 10 and 16 d in 1997 and 1998, respectively, when weeds were 8 to about 24 cm tall.

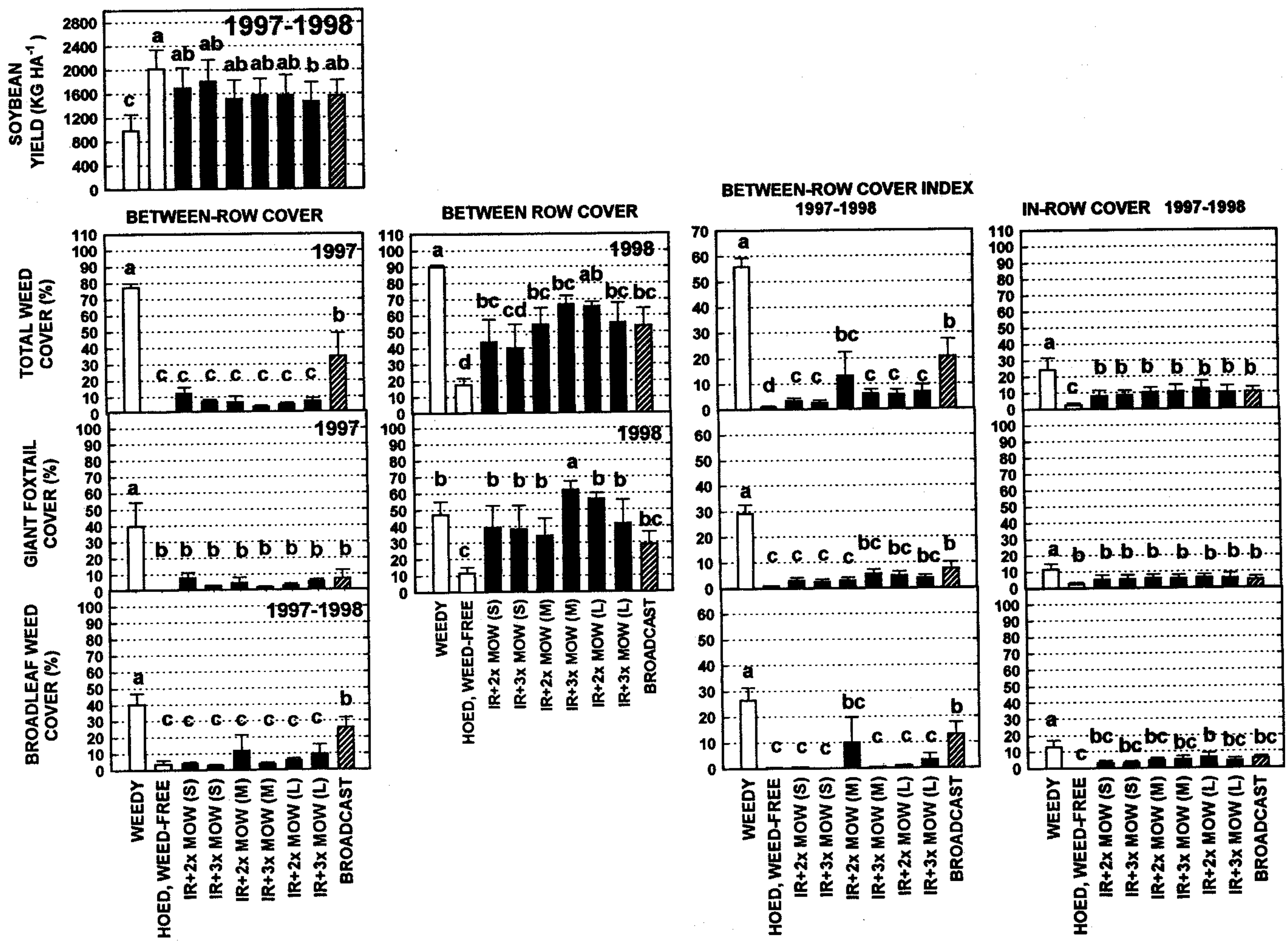

Fig. 2. Soybean yield (averaged across 1997 and 1998), between-row and in-row total weed, grass weed, and broadleaf weed cover (separately in 1997 and 1998), and cover index (weed cover [%] weighted by normalized weed height) (averaged across 1997 and 1998) graphed versus treatment. Means ± SE are presented. Means for each variable followed by the same letter were not different at $p = 0.05$ by Duncan's multiple range test. S, M, and L refer to relative weed height as defined in Table 2. IR = in-row band-applied herbicide, BR = between row.

Weed Cover

Most BR-mowing weed management systems in this study severely reduced total BR weed cover compared with the weedy check in both years (Fig. 2). However, total weed and grass weed cover were greater for BR mowed treatments in 1998 than in 1997. This is because the soybean canopy never completely closed in 1998 due to dry August conditions (Fig. 1). This allowed mowed weeds to regrow more between rows in 1998 than in 1997 when soybean canopy shading suppressed weed regrowth following the second BR mowing.

Incomplete soybean canopy closure allowed greater light intensities to reach the soil surface later in the growing season in 1998 than in 1997. Reportedly, greater light reaching the soil surface stimulated weed seed germination and enhanced subsequent growth, in contrast to well-shaded soil surfaces (Fenner, 1978). Crop management practices designed to encourage early, rapid soybean canopy closure to shade the soil surface may contribute to both weed suppression (Stoller et al., 1987) and the success of the BR-mowing weed management system (Fig. 2). When grown without crop shading, giant foxtail readily regrew from tillers to set seed following repeated cutting 5.1 cm above the soil surface at several growth stages (46 to 154 cm tall) (Schreiber, 1965). The cutting height used by Schreiber (1965), however, was much greater than that used in this research (about 2.5 to 3 cm). Mowing height, mowing timing, weed growth stage, crop shading, and crop interference all probably contributed to successful weed management in the BR-mowing weed management system.

In the BR-mowing weed management system, the first BR mowing killed most emerged annual broadleaf weeds but allowed some annual grass regrowth (Fig. 2 and 4, personal observation) (Donald 2000a,b). Most weed cover reductions were due to plant mortality (personal observation). A second BR mowing just before canopy closure was needed to suppress subsequent giant foxtail tiller growth from below the cutting height, which was missed by the first BR mowing. When the soybean canopy failed to close in 1998, shading was not complete enough to suppress subsequent giant foxtail cover development. In both years, annual grass and broadleaf weeds contributed roughly equally to total weed cover in the untreated weedy check.

Although BR total and grass weed cover were greater in 1998 than 1997 (Fig. 2), this cover was stunted in 1998. Consequently, BR weed cover index (Eq. [1]) described the relative effectiveness of treatments more realistically than did BR cover alone because cover index incorporated stunting. Year-by-treatment interactions prevented BR weed cover from being averaged, but cover index could be averaged because the year-by-treatment interaction was nonsignificant.

Reportedly, weeds growing close to soybean rows reduced yield more than those growing farther away (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). This assertion was tested by reexpressing the soybean yield data (Fig. 2) in terms of either IR or BR total weed cover for 1997 and 1998 across all treatments (Fig. 3). Because IR weeds competed and reduced soybean yield more than BR weeds, soybean yield should decrease much more over a lower, more restricted range of weed covers in crop rows than between rows. This was observed both years. Soybean yield without weed interference (i.e., the y intercept) was greater in 1997 than in 1998, presumably because August rainfall in 1997 was greater and more favorable for soybean flowering and seed formation than in 1998 (Fig. 1).

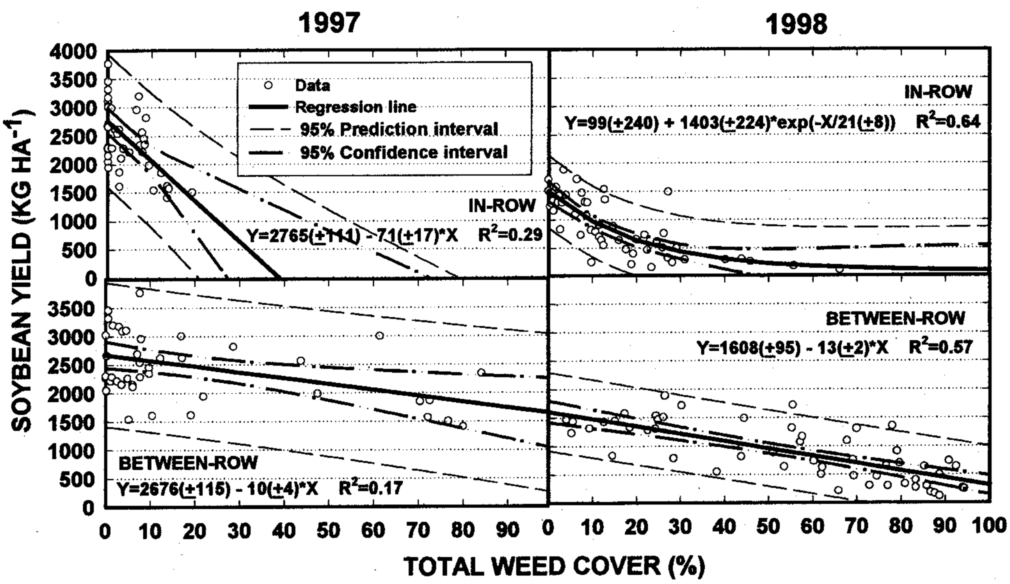

Fig. 3. Linear and nonlinear regression of soybean yield versus either in-row or between-row total midseason weed cover in 1997 and 1998. Data values (o), regression lines (——), 95% confidence intervals (......), and 95% prediction intervals (– – –) are presented with regression equations and coefficients of determination (r^2). Regression equation constants are presented ± standard errors.

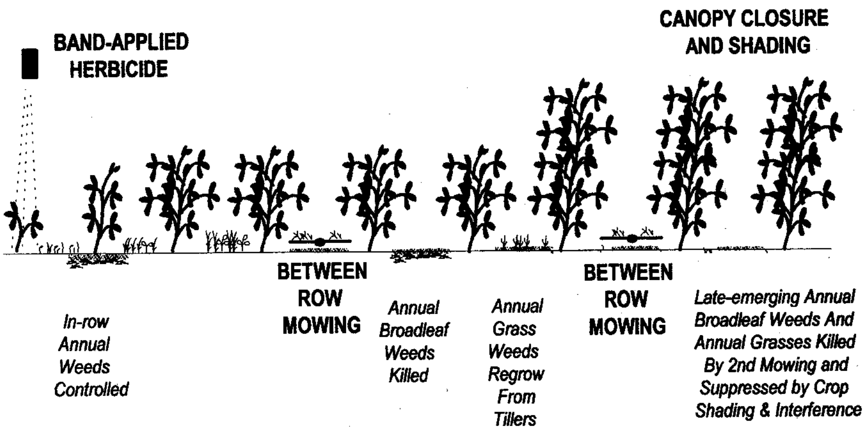

Fig. 4. Diagram of the components of the between-row-mowing weed management system in soybean over time until crop canopy closure.

Interference research shows that there is a period after crop emergence when annual weeds can grow with the crop without reducing yield (Oliver, 1988; Radosevich et al., 1997, p. 163–301; Zimdahl, 1980, p. 83–93). But after this early period ends, when weed removal is progressively delayed, yields become progressively reduced until no further yield loss occurs. Consequently, weeds must be removed before this period ends in order to maximize yield. When IR weeds are controlled early with band-applied herbicides, there is a relatively long, delayed window of opportunity for controlling BR weeds with close BR mowing (Fig. 2). Not only does IR interference reduce yield more than BR interference (Fig. 3), but observations presented in Fig. 2 suggest that IR interference may begin earlier than BR interference.

Early, complete crop shading and canopy closure probably give the crop a competitive advantage with weeds and contribute to the success of the BR-mowing weed management system. Some crops close canopy more quickly and more completely than others, however. Likewise, narrow row spacing encourages quicker canopy closure compared with wide row spacing. Environmental conditions, such as favorable soil moisture, also encourage early complete canopy closure. In fact, wide-row (i.e., 76 cm) soybean may not completely close canopy when water stressed, as in 1998. Crops that close canopy early and completely will likely require fewer BR mowings than those that fail to close canopy at all.

The BR-mowing weed management system has several advantages. Band-applied herbicide over crop rows reduced herbicide mass applied per unit area. While herbicide use was reduced by 50% in this BR-mowing weed management system, up to 60% reductions are possible with narrower bands. Properly timed, reduced-rate herbicide treatments may further decrease the herbicide mass applied per unit area. Reportedly, band application also reduced herbicide loss in runoff water and herbicide leaching into soil (Baker and Johnson, 1983; Gaynor and Wesenbeeck, 1995; Gaynor et al., 1995). By keeping annual weed and crop residue on the soil surface, BR mowing probably reduces the chance of soil erosion during the critical 30- to 45-d period after planting (Renard et al., 1994), when soil is most susceptible to erosion. Others noted the contribution of weed cover to preventing soil erosion, but usually after harvest or before planting (Dabney, 1998; Pannkuk et al., 1997; Zhu et al., 1989). Furthermore, the BR-mowing weed management system is compatible with no-tillage farming systems because it does not greatly disturb the soil surface.

A new weed management system, which consisted of (i) a competitive crop (soybean), (ii) band-applied herbicides over crop rows, and (iii) two close BR mowings, was optimized in this field study (Fig. 4). Between-row mowing very close to the soil surface twice with a mower killed or suppressed annual grass and broadleaf weeds, chiefly giant foxtail, common ragweed, and waterhemp species, when properly timed. When band-applied herbicide controlled weeds within crop rows, annual weeds between rows could be mowed twice (i.e., once when the tallest weeds were from 8 to 24 cm tall and again just before crop canopy closure), without yield loss. No more than two BR mowings were needed to control annual weeds. Shading by crop canopy closure contributed to weed suppression in this BR-mowing weed management system.

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