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Preemergence Banded Herbicides Followed by Only One Between-Row Mowing Controls Weeds in Corn[1]

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Abstract: Research was conducted to determine the minimum number of between-row mowings necessary to control annual weeds, chiefly giant foxtail and common waterhemp, without corn yield loss. Over 2 yr in Missouri, the between-row mowing systems that were evaluated consisted of a 38-cm band of PRE atrazine plus metolachlor at 2.2 plus 2.2 kg ai/ha applied over corn grown in 76-cm rows shortly after planting followed by one, two, or three between-row mowings close to the soil surface. Based on rated total weed control, between-row total weed cover, and corn yield, the weed-free check was statistically indistinguishable from a treatment in which banded PRE herbicide was followed by only one between-row mowing, late, when weeds were relatively large. When mowed once at 52 to 64 days after planting (DAP), giant foxtail and common waterhemp were greater than 85 cm tall. The yield was not increased by mowing earlier or more than once.
Nomenclature: Atrazine; metolachlor; giant foxtail, *Setaria faberii* (L.) Beauv. #[3] SETFA; common waterhemp, *Amaranthus rudis* Sauer. #[3] AMATA; corn, *Zea mays* L. 'Pioneer 3379' #ZEAMX.
Additional index words: Alternative weed control, banding, banded application, cutting, mechanical weed control, nonchemical weed control, reduced rate herbicide.
Abbreviations: BR, between row; IR, in row.

INTRODUCTION

In the Corn Belt, most producers rely on broadcast-applied herbicides to control weeds in field corn (USDA-NASS 2004a). For example, Missouri corn producers treated 95% of the total corn hectareage with herbicides from 1990 to 2002. However, the general public fears that herbicides applied to corn and other field crops will contaminate surface and ground water (Logan et al. 1987; Richards and Baker 1993). Some drinking water suppliers have been forced to pay clean-up costs for herbicide contamination of water. Reducing total herbicide use will minimize inadvertent water contamination by soil-residual corn herbicides, such as atrazine (Logan 1993). This reduction can be achieved by (1) decreasing the area treated with herbicides and substituting mechanical weed control methods, (2) reducing herbicide rate and changing application timing, or (3) substituting different herbicides that are less likely to contaminate water. There is an urgent national need to find new alternative ways to manage weeds to help farmers minimize herbicide contamination of water without sacrificing farmers' economic goals. The research reported in this article focused on the first tactic: decreasing the area treated with herbicides by substituting mechanical weed control methods. Mechanical weed control methods between rows, such as cultivation, can reduce the herbicide-treated area by 50%. Moreover, banding PRE herbicides followed by properly timed cultivation did not reduce corn yields compared to broadcast herbicides or weed-free checks (Bicki et al. 1991; Eadie et al. 1992; Ford and Mt. Pleasant 1994; Hanna et al. 2000; Leblanc et al. 1995; Logan 1993; Moomaw and Robison 1973; Mulder and Doll 1993; Paarlberg et al. 1998). The practice of banding PRE herbicides followed by cultivation decreased both herbicide leaching through the soil profile and herbicide loss in runoff water from fields (Gaynor and Wesenbeeck 1995).

Although cultivation can help reduce herbicide contamination of water, cultivation itself has negative environmental effects, and widespread adoption by farmers is unlikely. Negative effects include soil erosion and increased sediment and nutrient losses in runoff from fields (Belvins et al. 1998). Cultivation also is incompatible with no-tillage, unless specialized cultivators are used (Hanna et al. 2000; Paarlberg et al. 1998). In farmer surveys conducted during the mid-1990s, Missouri corn

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[3] Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds*, Revised 1989. Available only on computer disk from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

farmers reported that banded herbicides followed by cultivation were unacceptable (Rikoon et al. 1996). In 2003, only 17% of corn hectareage was cultivated in Missouri (Napier et al. 2000; USDA-NASS 2004b), although up to 60% of corn hectareage is cultivated in other states, even after broadcast herbicide application.

Research in soybean [*Glycine max* (L.) Merr.] and corn showed that 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 were statistically indistinguishable between weed-free checks, broadcast herbicide treatments, and certain treatments consisting of banded PRE herbicide followed by between-row mowing. Unlike conventional cultivation, banded PRE herbicide followed by between-row mowing was compatible with no-tillage (Donald et al. 2001). Two properly timed between-row mowings close to the soil surface before crop canopy closure killed common annual weeds, including giant foxtail, common ragweed (*Ambrosia artemisiifolia* L. #AMBEL), and common waterhemp. If they ever become commercialized, between-row mowers may have potential use in alternative weed management systems for competitive, upright-growing row crops.

In this research, weed management systems consisting of banded PRE herbicide followed by between-row mowing were optimized for corn grown in 76-cm rows with conventional tillage. The research objective was to determine the minimum number of between-row mowings that were needed to control weeds and prevent yield loss. The null hypothesis was that the yield would be maximum for the weed-free checks and a system that was mowed only once. The alternative hypothesis was that two or more between-row mowings would be required to adequately control weeds and prevent yield loss. Between-row total weed cover was expected to be ranked: weed-free check $\leq$ between-row mowing systems $\ll$ weedy check. For rated total weed control, this rank order was expected to be reversed.

MATERIALS AND METHODS

Site, Weather, and Weeds. In 1994 and 1995, corn was planted in rotation after soybean 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 in 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 pHs of 5.5 to 5.8. Soil pHs are salt pH values that run approximately 0.5 units lower than the customary water pH values.

Historical weather data were collected at Bradford (Figure 1). However, 1995 data from the nearby Sanborn Experimental Field were substituted in 1995 because weather data were incomplete at Bradford. 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 corn planting until harvest using a base temperature of 10 C (Ruiz et al. 1998).

Giant foxtail was the major grass weed present. Barnyardgrass [*Echinochloa crus-galli* (L.) Beauv. #ECHCG], fall panicum (*Panicum dichotomiflorum* Michx. #PANDI), and large crabgrass [*Digitaria sanguinalis* (L.) Scop. #DIGSA] were very minor, scattered grass problems. Common waterhemp was the major broadleaf weed present, and common cocklebur (*Xanthium strumarium* L. #XANST), common ragweed, ivyleaf morningglory [*Ipomoea hederacea* (L.) Jacq. #IPOHE], ladysthumb (*Polygonum persicaria* L. #POLPE), and velvetleaf (*Abutilon theophrasti* Medik. #ABUTH) were sparse and scattered.

Agronomic Practices. In either fall or spring, the site was chisel plowed or disced, and in spring the site was field cultivated for seedbed preparation (Table 1). Corn was fertilized with N-P-K for a grain yield goal of 8,070 kg/ha based on soil tests and recommendations of the University of Missouri soil testing lab. N-P-K was broadcast before planting at 140:22:0 kg/ha and 134:0:0 kg/ha in 1994 and 1995, respectively, and was incorporated by cultivation. 'Pioneer 3379' corn seed was planted 4 to 5 cm deep in 76-cm rows at 75,600 and 78,150 seeds/ha in 1994 and 1995, respectively.

Treatments. Treated plots measured 3 × 9.1 m. Between-row mowing systems consisted of (1) a competitive crop and (2) PRE herbicides banded over crop rows followed by (3) between-row mowing after weeds became tall enough to mow. Banded PRE atrazine plus metolachlor at 2.2 plus 2.2 kg/ha was applied to all between-row mowing treatments in 38-cm-wide bands over 76-cm corn rows so that bands slightly overlapped the between-row mowed zone (Table 1). A bicycle wheel sprayer was operated at 4.8 km/h using compressed CO_2 at 276 kPa to apply spray volumes of 133 to 136 L/ha water with even flat-fan nozzles.[4] For banding, the boom height was 23 cm.

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

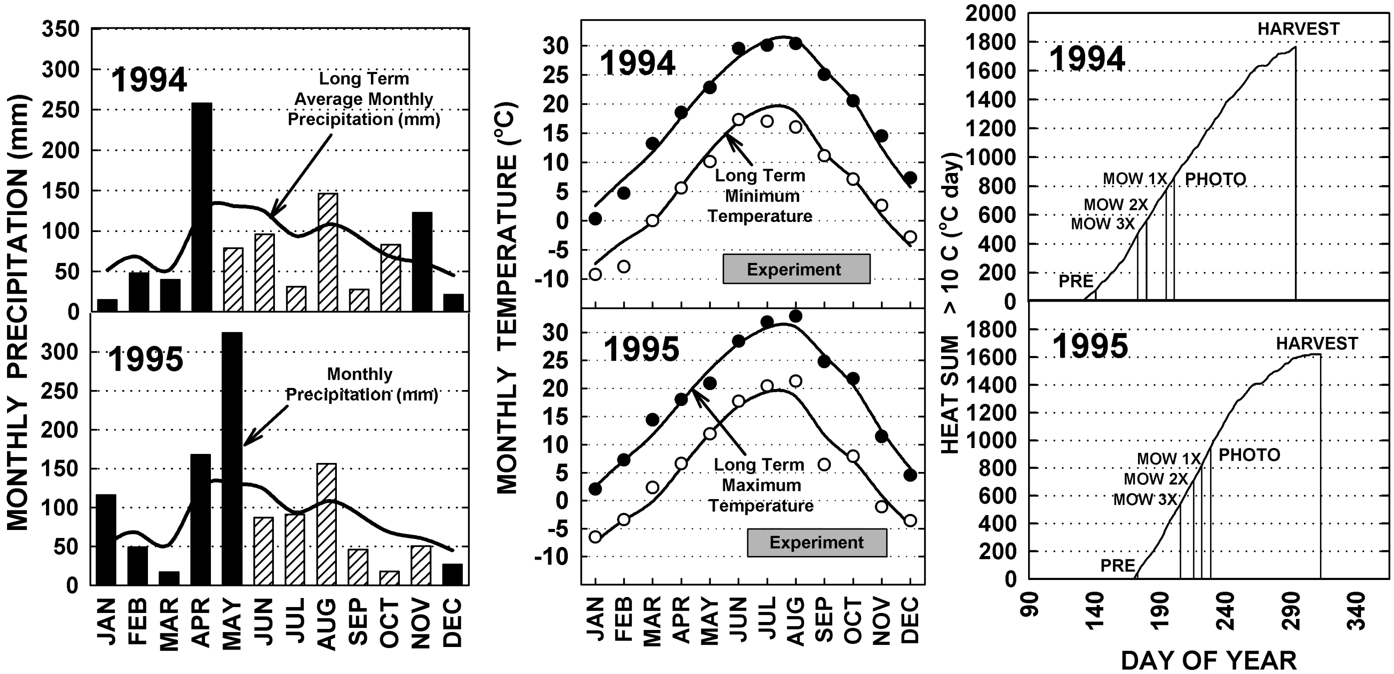

Figure 1. In the left panels, monthly precipitation (bars) and long-term average monthly precipitation (lines) are graphed vs. month of the year. In the middle panels, monthly average maximum and minimum air temperatures (solid and open circles, respectively) and long-term averages (lines) are graphed vs. month of the year. In the right panels, heat sums greater than 10 C after corn planting are graphed vs. day of the year. Long-term averages were for 1993 to 2001. The hatched bars (left panels) and horizontal bars (middle panels) show the duration of the experiments. Abbreviations: PRE, preemergence herbicides applied; MOW, between-row mowing imposed; PHOTO, photographs taken.

When between-row mowing treatments were imposed, the PRE herbicide-treated zone was weed-free. The treatments were three (3×), two (2×), and one (1×) between-row mowings (Table 1). All between-row mowing treatments ended at the same time, just before corn canopy closure. Because both numbers of mowings and start times were confounded, treatments are different ‘‘systems.’’

Differences in corn planting dates and heat sums (Figures 1 and 2) caused weed growth rates to differ between years. Consequently, between-row mowing treatments started at different times, and the interval between mow-

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

	1994		1995	
Field operations, treatments, or measurements	Date	DAP[a]	Date	DAP[a]
Plant corn	5/11/94	0	6/19/95	0
Apply PRE atrazine plus metolachlor	5/21/94	10	6/22/95	3
Corn emergence	5/25/94	14	6/26/95	7
Between-row weed mowing:				
3× Between-row mow weeds	6/22/94	42	7/25/95	36
Re-mow weeds	6/29/94	49	8/4/95	46
Re-mow weeds	7/14/94	64	8/10/95	52
2× Between-row mow weeds	6/29/94	49	8/4/95	46
Re-mow weeds	7/14/94	64	8/10/95	52
1× Between-row mow weeds	7/14/94	64	8/10/95	52
In weed-free check plots, how and hand pull weeds:	6/13/94	33	7/13/95	24
Re-how and hand pull weeds	6/17/94	37	7/18/95	29
Re-how and hand pull weeds	6/22/94	42	7/25/95	36
Re-hoe and hand pull weeds	6/29/94	49	8/4/95	46
Re-how and hand pull weeds	7/7/94	57	8/10/95	52
Photograph between-row weed cover	7/20/94	70	8/17/95	59
Rate weed control	7/21/94	71	8/18/95	60
Harvest corn	10/21/94	163	11/9/95	143

[a] Abbreviation: DAP, days after planting.

ings differed between years. Although 1995 corn was planted about 1 mo later than in 1994, between-row mowing was started later after planting in 1994 than in 1995 (33 vs. 25 d after planting, respectively), even though heat sums were lower by that time (316 vs. 370 degree C days, respectively) (Figures 1 and 2).

A plastic cord mower[5,6] was used to mow between-row weeds about 3 cm above the soil surface. The between-row mowing width was 60 cm, leaving about 8 cm unmowed on either side of 76-cm-wide crop rows. When first mowed between rows, corn and weed heights between years differed slightly (Figure 2). After weed regrowth became 7 to 15 cm tall, between-row mowing was repeated for the 2× and 3× treatments.

The experiment included weedy and weed-free checks, in which seedbed preparation killed all weeds present at planting. ''Weed-free'' checks were shallowly hoed between rows, and in-row weeds were hand pulled several times during the growing season until corn silking (Table 1). Although these ''hand-weeded'' plots were not completely ''weed-free'' by harvest, weeds emerging after silking and canopy closure do not reduce corn grain yields (Bedmar et al. 1999; Hall et al. 1992).

Measurements. At mid-season, total weed control was visually evaluated based on a scale of 0% (no control) to 100% (complete kill) (Table 1). After cutting borders at either end of all plots, corn was combine harvested from 8.2 m of the two center rows, and grain yields were adjusted to 15% moisture content.

Projected between-row weed ground cover was used to measure treatment efficacy (Table 1). Projected ground cover of between-row grass, broadleaf, and total weeds (i.e., grass plus broadleaf weeds), but not crop cover, was measured from photographs taken between crop rows (Table 1). Corn 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 19 cm out at a right angle from the crop row just above the soil surface toward the row middle to mark the herbicide band in the photographs. Four between-row photographs per plot were taken vertically (i.e., camera facing toward the soil surface) with video or digital cameras,[7] respectively, at a height of 144 cm. Each photograph corresponded to 0.8 m^2 at the soil surface based on photographs of a 30 × 30–cm orange calibration plate. Image analysis software[8] was used to crop between-row zones and automatically superimpose a 20 × 20–pixel grid over each cropped photograph. Total weed cover was calculated as the per-

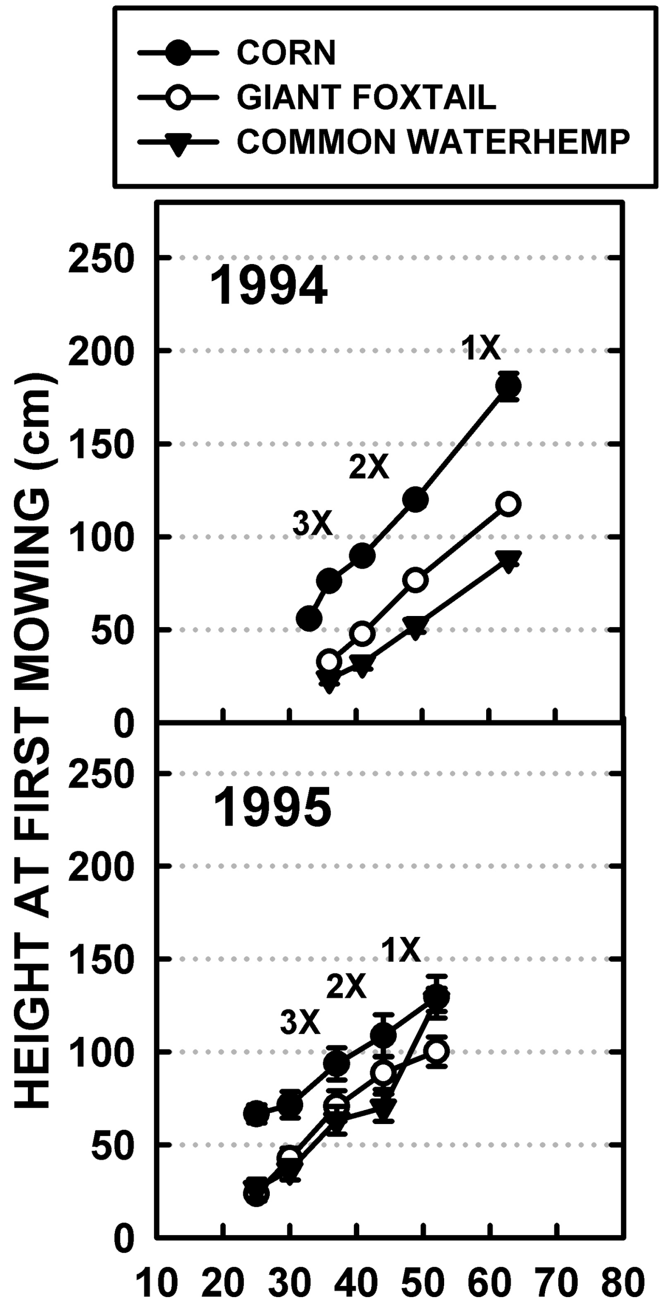

Figure 2. Heat sums of >10 C (C days) before and at the initial between-row mowing treatment (days after planting) in 1994 and 1995 (left panels). Height of corn, giant foxtail, and common waterhemp (means ± standard errors) before and at the initial between-row mowing treatment (days after planting). Times when treatments were first mowed are shown for different numbers of mowings (1× to 3×).

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

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

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

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

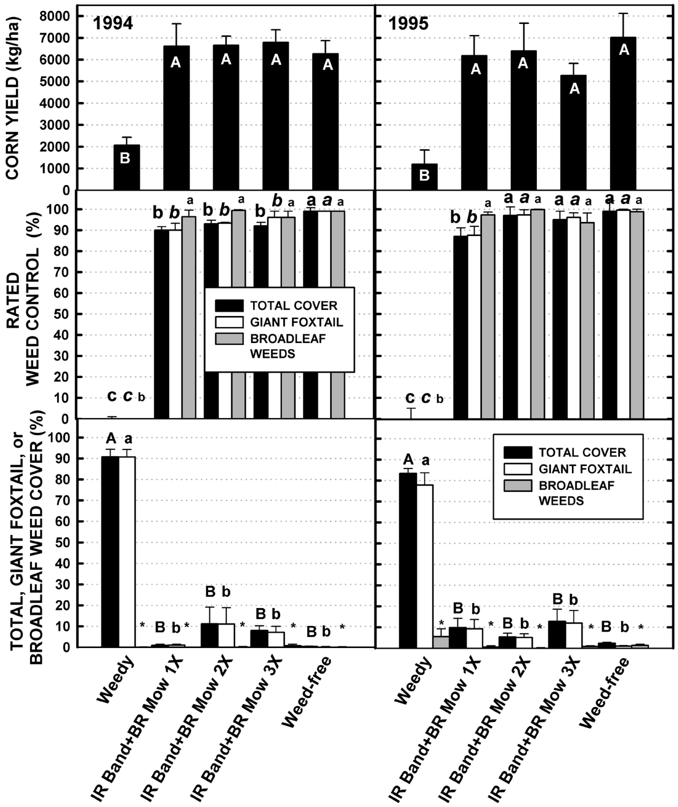

Figure 3. Effect of between-row mowing treatments on corn yield, rated total weed control, and between-row weed cover of giant foxtail, broadleaf weeds, and all weeds in 1994 and 1995. Within a year, means (± standard errors) with the same letter (different fonts or cases for different measurements) were not different at P = 0.05 by Fischer's protected LSD. Within a year, between-row broadleaf weed cover for all treatments were statistically indistinguishable (*). Abbreviations: BR, between row; IR, in row band herbicide.

cent of grid points intersected by grass or broadleaf weeds. Weed cover (%) is presented as the average of four between-row photographs per plot.

Statistical Analysis. The experimental design was a randomized complete block with three blocks, and blocking was based on slope position and weed ground cover observed in preceding years (Hoshmand 1994). Corn yields, rated weed control, and between-row weed cover were subjected to ANOVA using statistical software.[9] Means were separated by Fisher's protected LSD test at P = 0.05.

RESULTS AND DISCUSSION

Although corn stands were only 75 and 80% of planting intentions in 1994 and 1995, corn yields of the weed-free checks were 89 and 87% of the yield goal, for which the experiment was fertilized, respectively (Figure 3). Timely hoeing and hand weeding kept weed cover less than 5% in the weed-free checks at mid-season and prevented yield loss due to weed interference (Figure 3). In both years, annual weeds greatly reduced corn yields in weedy checks, as expected. In 1994 and 1995, corn yields of the weedy check were 30 and 15% of the weed-free checks, respectively. In both years, corn yields of all between-row mowing treatments exceeded the weedy check and were statistically indistinguishable from the weed-free check and each other.

In 1994, rated total weed control and giant foxtail control of all between-row mowing treatments were greater than 90% and less than the weed-free check (Figure 3). In 1995, rated total weed control and giant foxtail control of the weed-free check were statistically indistinguishable from the 2× and 3× between-row mowing treatments and greater than the 1× between-row mowing treatment. All treatments other than the weedy check exceeded 85%. In both years, broadleaf weed control exceeded 95% in all treatments and was statistically indistinguishable from the weed-free check.

Most weed scientists rate weed control on a percentage basis as weed biomass or volume compared to a weedy check. For the purpose of making treatment recommendations, rated weed control is a subjective judgment of whether treatments would be acceptable to farmers who wish fields to be free of weeds. Total weed, giant foxtail, and broadleaf weed cover provided different information than rated weed control about weed response to treatment and yield limiting factors.

The effects of between-row mowing treatments on rated weed control were the inverses of treatment effects on weed cover (Figure 3). From rated weed control, one cannot ascertain whether giant foxtail or broadleaf weeds were more common and whether broadleaf weeds were more related to yield loss than was giant foxtail. Likewise, rated control of the weedy checks was taken as 0% in both years and cannot distinguish between-year differences in weed populations. In contrast in 1994, total weed cover in the weedy checks was 91% and consisted entirely of giant foxtail. In 1995, total weed, giant foxtail, and broadleaf weed cover were 83, 78, and 5%, respectively. Thus, total weed cover was less in 1995 than in 1994, but, again, most weed cover was giant foxtail. In both years, corn yield losses were due to giant foxtail, not broadleaf weeds.

By mid-season, between-row mowing treatments reduced total weed cover below 15%, and between-row mowing treatments were statistically indistinguishable from the weed-free check (Figure 3). This amount of

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

total weed cover did not reduce corn yields. As in the weedy check, most total weed cover escaping between-row mowing treatment was giant foxtail. Mowing controlled annual broadleaf and grass weeds differently. The first mowing killed most emerged broadleaf weeds, including common waterhemp, the major broadleaf weed present, as well as common cocklebur, common ragweed, ivyleaf morningglory, ladysthumb, and velvetleaf. After mowing, corn canopy closure and later shading likely limited subsequent germination and emergence of these broadleaf weeds. Following one mowing, giant foxtail regrew from tiller buds present in the crown close to the soil surface, below the mowing height. In previous research (Donald 2000a, 2000b; Donald et al. 2001), a second between-row mowing killed the giant foxtail that survived the first mowing. Corn shading likely limited subsequent giant foxtail germination, emergence, and recovery from mowing (Santelmann et al. 1963).

Based on corn yield or between-row total weed cover, there was no advantage to mowing weeds more than once (1×) (Figure 3). When in-row weed emergence was reduced and delayed by banded PRE herbicides, only a single, properly timed between-row mowing was required to prevent yield loss. At 64 DAP in 1994 (777 C days), giant foxtail and common waterhemp growing between rows were 117 and 88 cm tall, respectively (Figure 2). At 52 DAP in 1995 (840 C days), giant foxtail and common waterhemp were 100 and 129 cm tall, respectively, between rows.

Research on the timing of giant foxtail competition in corn (Knake and Slife 1965, 1969; Rajcan and Swanton 2001) was not helpful in interpreting these results and explaining why one between-row mowing could be delayed so long after planting without corn yield loss (Figures 2 and 3). In most competition research, weeds were allowed to emerge and grow from the time of planting either in corn rows or in the entire plot. In addition, weeds were not usually treated with soil-residual PRE herbicides, which reduce and delay weed emergence. In contrast, banded PRE herbicides in between-row mowing systems kept corn rows weed-free until well after between-row weeds were mowed (Donald et al. 2001). In these treatments, corn emerged well before between-row weeds emerged. Only one report included treatments in which corn rows were kept free of weeds, and weeds were allowed to grow between rows from planting until harvest (Donald and Johnson 2003). When in-row weeds were controlled, but between-row weeds competed with corn until harvest, between-row weeds reduced corn yields as much or more than when between-row weeds were controlled, but in-row weeds competed until harvest. In-row or between-row competition reduced corn yields less than when weeds competed both in and between rows until corn harvest. Although it remains to be proven, between-row weeds are likely to begin to compete with corn later than weeds growing adjacent to corn plants in the row. If in-row weeds are controlled with banded PRE herbicides, the window of opportunity for controlling late-emerging weeds between rows was extended, without yield loss (Figures 2 and 3), compared with prior competition research (Knake and Slife 1965, 1969; Rajcan and Swanton 2001).

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