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Banded herbicide, rotary hoeing and cultivation effects on weed populations in ridge-tilled soybean

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Abstract

Can banded herbicide be eliminated in ridge-tilled soybean (*Glycine max*)? The effects of banded herbicide, rotary hoeing and cultivation on weed populations and soybean yield in a ridge-tillage system were tested on three farms in Iowa, USA in 1989 and 1990. In 1989, plots either had no herbicide or had herbicide banded in the row at planting in mid-May; all plots received two rotary hoeings and two cultivations. In 1990, treatments were banded herbicide with no rotary hoeing, banded herbicide with one rotary hoeing, and no herbicide with one or two rotary hoeings; all plots received two or three cultivations. In both years, over all weed species [primarily giant foxtail (*Setaria faberi*), Pennsylvania smartweed (*Polygonum pensylvanicum*) and redroot pigweed (*Amaranthus retroflexus*)], seedling emergence was highest in late May and early June, with few seedlings emerging after mid-June. Weed populations were highest in May and June, after which rotary hoeing and cultivation reduced weed numbers in all plots. There were no consistent differences among treatments in weed numbers in early August for the 2 years. In both years, there was no significant difference in soybean yield among treatments. Within-farm mean yields ranged from 2.26 to 3.01 Mg ha^{-1} among farms in 1989 and from 2.07 to 2.93 Mg ha^{-1} among farms in 1990. Ridge-tillage without herbicide was generally equivalent to ridge-tillage with banded herbicide, with respect to total number of weeds and number of broad-leaved weeds remaining in August after tillage, and to soybean yield.

Key words: conservation tillage, mechanical weed control, seedling emergence, weed density, weed population dynamics

Introduction

Ridge-tillage has been used to a limited extent since the 1950s in the midwestern USA[1]. It may provide an alternative to extensive use of herbicide to control weeds. However, wider adoption of ridge-tillage has been slowed by a variety of concerns, including tillage costs, long-term effects on weed populations, and lack of knowledge of the best combinations of techniques to use in the system. Despite the fuel, labor and machinery costs associated with its tillage operations, ridge-tillage appears to be an economically viable system, with returns competitive with those of other tillage systems[2].

The effectiveness of ridge-tillage relative to other tillage systems in controlling weeds has been examined in several studies[3–5]. There has been concern that reduced-tillage systems will require more herbicide to control weeds. This may occur in no-till systems[6]. However, the mechanical operations of ridge-tillage can greatly reduce the number of weeds present, such that a ridge-tillage system with herbicide banded in the row may control weeds as well as ridge-tillage with broadcast herbicide[7]. Can herbicide applications be further reduced in a ridge-tillage system? Rotary hoeing is often used to control weeds in ridge-tillage systems, after planting has produced a relatively flat surface topography; cultivations to rebuild the ridges further control weeds. However, little information is available on how well weeds are controlled by rotary-hoeing and cultivation in a ridge-tillage system and whether herbicide can be eliminated. The combination of rotary hoeing and cultivation provided good weed control in moldboard-plowed soybeans[8] and chisel-plowed corn[9], even when reduced herbicide rates were used.

The objective of this study was to contrast ridge-tillage with and without herbicide banded in the row at planting, to evaluate whether rotary hoeing and cultivation are an effective substitute for banded herbicide with respect to weed control and soybean (*Glycine max*) yield.

Table 1. Soybean cultivars and herbicides used, cultural conditions, plant densities and rainfall in 1989 on three farms in Iowa.

	Farm		
	Graaf	**Grau**	**Hartsock**
Cultivar	Pioneer 1981	Hill 2275	Soi 226
Herbicide	Chloramben	Metolachlor + metribuzin	Metolachlor
Herbicide rate (kg ha^{-1})[1]	0.79[2]	0.57[3] + 0.08[3]	0.91[3]
Herbicide band width (cm)	15	30	25
Mean row width (cm)	76	100	91
Row length (m)	800	400	400
Rows/plot	6	8	8
Seeding rate (number ha^{-1})	507,000	378,000	395,000
July soybean plant density (number ha^{-1})			
with banded herbicide[4]	264,000	284,000	329,000
without herbicide[4]	262,000	287,000	297,000
Rainfall (cm)			
May	4.8[5] (9.3)[6]	3.6 (9.3)[6]	1.8 (9.3)[6]
June	6.1[5] (11.2)[6]	7.6 (11.2)[6]	4.3 (11.2)[6]
July	7.5[5] (9.7)[6]	7.7 (9.7)[6]	3.8 (9.7)[6]
August	4.6[5] (10.4)[6]	4.8 (10.4)[6]	7.2 (10.4)[6]

[1] Rate per unit herbicide band area.
[2] kg a.e. ha^{-1}.
[3] kg a.i. ha^{-1}.
[4] Treatments also received rotary hoeing and cultivation.
[5] Values from Pocahontas, Iowa (US National Climatic Data Center).
[6] Long-term normal value for Pocahontas, Iowa (US National Climatic Data Center).

Materials and Methods

Field sites

Four privately owned and operated farms were used for field studies in 1989 and 1990. The Graaf farm was near Palmer and Pocahontas, the Grau farm near Newell, the Hartsock farm near Rolfe, and the Thompson farm near Boone, Iowa, USA. Farmers used their own equipment, seed and herbicide to establish, grow and harvest soybean on the field sites. Corn–soybean (Graaf, Grau and Hartsock farms) or corn–soybean–corn–oats–hay (Thompson farm) rotations had been used on the sites. Different fields on each farm were used in 1989 and 1990. A severe rain storm on 23 May 1989 potentially damaged the treatments on the Thompson farm, so the experiment was terminated on that site for that year. Similarly, a severe wind/hail storm on 19 June 1990 destroyed the Graaf farm experiment. Thus, data are available for only three farms in each year. In 1989, plots on the Graaf, Grau and Hartsock farms were primarily on Clarion (fine-loamy, mixed, mesic Typic Hapludolls) and Webster (fine-loamy, mixed, mesic Typic Haplaquolls) soils[10,11]. The Hartsock field also included some Nicollet soil (fine-loamy, mixed, mesic Aquic Hapludolls), and the Grau farm also included some Nicollet and Canisteo [fine-loamy, mixed (calcareous), mesic Typic Haplaquolls] soils. In 1990, the Thompson farm plots were on Clarion and Webster soils[12], while the Hartsock and Grau farm plots were on Canisteo soil.

Experimental treatments

Soybean cultivars, herbicides used, cultural conditions, plant densities and May–August rainfall for the study farms are shown in Table 1 for 1989 and in Table 2 for 1990. Although the soybean cultivars and most of the herbicides used in this study generally have been replaced by others in the years since 1990, a key point noted below in the Results and Discussion is that all the herbicide treatments in the ridge-till system provided good to excellent weed control and thus provided a standard of reference similar to what might be expected when using current formulations of herbicides and crop varieties in a ridge-till system. Rainfall was recorded by each farmer. Rainfall values were compared with long-term mean values from Pocahontas, Iowa (located between the Graaf, Grau and Hartsock farms) and Boone, Iowa (near the Thompson farm), as reported by the US National Climatic Data Center. Seeding rates are values reported by the farmers. Dates of planting, rotary hoeing and cultivation are given in Table 3. Herbicide was banded in the row at planting, in those treatments receiving herbicide. On each site, there were six replications of each treatment, arranged in a randomized complete block design, with each set of two (in 1989) or three (in 1990) treatment plots constituting a block. Each replicate plot consisted of six or eight rows, 400 m or 800 m in length (Tables 1, 2). All rows were oriented N–S except on the Graaf farm, where they ran E–W. Soybean plant densities in July 1989 and early August 1990 were estimated from counts in three 5-meter lengths of row in each plot.

Table 2. Soybean cultivars and herbicides used, cultural conditions, plant densities and rainfall in 1990 on three farms in Iowa.

	Farm		
	Grau	**Hartsock**	**Thompson**
Cultivar	Latham 750	Latham 671	Mohawk
Herbicide	Metolachlor + metribuzin	Metolachlor	Chloramben
Herbicide rate (kg ha^{-1})[1]	0.57[2] + 0.08[2]	0.76[2]	0.79[3]
Herbicide band width (cm)	30	20	20
Mean row width (cm)	91	91	91
Row length (m)	800	800	400
Rows/plot	8	8	8
Seeding rate (number ha^{-1})	395,000	430,000	445,000
August soybean plant density (number ha^{-1})			
banded herbicide, 0 rotary hoeing[4]	259,000	299,000	221,000
banded herbicide, 1 rotary hoeing[4]	219,000	319,000	203,000
no herbicide, 1 or 2 rotary hoeings[4]	212,000	264,000	206,000
Rainfall (cm)			
May	11.3 (9.3)[5]	11.2 (9.3)[5]	21.1 (11.1)[6]
June	35.2 (11.2)[5]	18.8 (11.2)[5]	23.1 (13.0)[6]
July	7.8 (9.7)[5]	11.9 (9.7)[5]	12.2 (8.8)[6]
August	16.0 (10.4)[5]	8.6 (10.4)[5]	6.7 (9.9)[6]

[1] Rate per unit herbicide band area.
[2] kg a.i. ha^{-1}
[3] kg a.e. ha^{-1}
[4] Treatments also received cultivation.
[5] Long-term normal value for Pocahontas, Iowa (US National Climatic Data Center)
[6] Long-term normal value for Boone, Iowa (US National Climatic Data Center).

In 1989, the experimental treatments were either herbicide banded over the row at planting or no herbicide was used. All plots received two rotary hoeings, in late May and early June, and two ridge-building cultivations, in June and early July (Table 3). In 1990, three experimental treatments were used. Treatments were herbicide banded over the row, with no rotary hoeing but two cultivations; herbicide banded over the row, with one rotary hoeing and two cultivations; and no herbicide, with two rotary hoeings and two cultivations. However, wet spring weather caused the number of rotary hoeings and cultivations to vary among farms in the no herbicide treatment. On the Grau and Hartsock farms, one rotary hoeing and three cultivations were used instead of the planned sequence of two rotary hoeings and two cultivations (see Table 3).

Table 3. Dates of planting, rotary hoeing and cultivation in 1989 and 1990 on four farms in Iowa.

	Farm			
	Graaf	**Grau**	**Hartsock**	**Thompson**
1989				
Planting	12 May	13 May	17 May	–
Rotary hoeing				
First	19 May	16 May	19 May	–
Second	24 May	31 May	28 May	–
Cultivation				
First	10 June	9 June	14 June	–
Second	22 June	5 July	1 July	–
1990				
Planting	–	30 May	5 June	1 June
Rotary hoeing				
First	–	25 June	25 June	4 June
Second	–	–	–	25 June
Cultivation				
First	–	6 July	5 July	27 June
Second	–	15 July	22 July	17 July
Third	–	1 August	30 July	–

Weed populations

Weed populations were sampled from late April to early August, after which there was essentially no further seedling emergence and no tillage operations. From planting through July, sampling was timed as much as possible to occur the day before tillage operations. Each plot was sampled a total of nine times in 1989 and 12 times in 1990. Sample locations within a plot varied among dates, to avoid a repeated-measures design. A rectangular sample area was defined as the distance between two rows of soybean plants × a distance along a row. Distance along a row, and hence size of the area sampled in each plot, varied over the growing season, but was uniform within a farm during any one sampling date. Total area sampled in each plot typically was 4–12 m^2 in May and June when seedling densities were high, but in late July and August was as large as 600 m^2 in each plot (nearly 1/10 the total plot area) when weed densities were much lower. The increase in

Table 4. Common weed species present at four farms in Iowa in 1989 (x) and 1990 (y). Foxtail species, Pennsylvania smartweed and redroot pigweed together typically constituted >90% of the weeds present on a site. Other species in the table were often present but had low abundances. Nine other species (not shown) were recorded only sporadically. The Thompson and Graaf farms were not studied in 1989 and 1990, respectively.

	Farm			
Taxon	**Graaf**	**Grau**	**Hartsock**	**Thompson**
Common cocklebur (*Xanthium strumarium* L.)	x	y	x	y
Common lambsquarters (*Chenopodium album* L.)	x	x	xy	y
Foxtail species (*Setaria* spp.)	x	xy	xy	y
Kochia (*Kochia scoparia* (L.) Schrad.)		xy	xy	
Pennsylvania smartweed (*Polygonum pensylvanicum* L.)	x	xy	xy	y
Redroot pigweed (*Amaranthus retroflexus* L.)	x	xy	xy	y
Smooth groundcherry (*Physalis subglabrata* Mack. and Bush.)	x	xy	xy	y

sample area decreased the variability among samples that would otherwise have occurred if smaller sample areas had been used with the low weed densities in late July and August.

On each sampling date, number of seedlings (plants < 2 cm tall) and plants >2 cm tall of all weed species were recorded in each sample area. The 'seedlings' category thus included plants that were presumed to have emerged since the previous sample date, and graphs of seedlings present (see Results) can be interpreted as approximate rates of seedling emergence. Patterns of emergence based on this procedure were similar to patterns derived in 1990 from small (0.25 m^2) subplots on the sites in which seedlings were counted and removed on each sample date (data not shown). The category of 'plants >2 cm' includes plants of various ages and sizes that may have survived previous tillage operations.

Statistical analyses

Within a year, values for weed populations on 1 August or for soybean yield (13% moisture) were compared over all farms using analysis of variance (ANOVA)[13] for a nested design, with main effects of farms, blocks (nested within farms) and herbicide/rotary hoeing treatment and a farm × herbicide/rotary hoeing treatment interaction term (alpha = 0.05).

Results and Discussion

Rainfall in 1989 (Table 1) was lower than normal on all farms but was distributed fairly evenly over the growing season on all farms, so that soybeans exhibited no apparent symptoms of moisture stress. In 1990, rainfall was above normal in May and early June but was near normal after mid-June (Table 2). In general, the same weed species were found on a given farm in both years (Table 4), although there was some variation because different fields were used each year. Foxtail species (*Setaria* spp.), Pennsylvania smartweed (*Polygonum pensylvanicum* L.) and redroot pigweed (*Amaranthus retroflexus* L.) were found on all four farms and typically totalled >90% of the weeds on a site; values for those taxa are presented here. Other species were much less common, but are included in the totals over all species. Foxtail species included primarily giant foxtail (*Setaria faberi* Herrm.), with lesser amounts of green foxtail [*Setaria viridis* (L.) Beauv.] and yellow foxtail [*Setaria glauca* (L.) Beauv.]; values for these taxa are here combined and called 'foxtail species'. Giant foxtail was the most common foxtail species found as adult plants. No other genus of grass was commonly found. Thus, the total number of broad-leaved individuals presented below is essentially the total number of individuals of all species minus the number of individuals of foxtail species. Conservation tillage systems[14] such as ridge-tillage may differ in the weed species present[15], because of differences in selection regimes and growth conditions, but there are no unique problems presented by ridge-tillage in this respect, and the weed species recorded here are commonly found throughout the state.

Patterns of weed population numbers were similar in 1989 and 1990 on all farms, except that in 1990 seedling emergence in late spring was slightly later due to weather conditions. Patterns for 1990 on the Hartsock farm (Fig. 1) illustrate the general pattern found in both years for total numbers of weeds found by herbicide/rotary hoeing treatment, over all species. Results for individual species had similar patterns, except that different species had different times of peak seedling emergence. Seedlings appeared in greatest numbers from mid-May to early June, with practically no seedlings appearing in April or after the last cultivation in late July (Fig. 1a). Patterns of seedling numbers were very similar for the banded herbicide and no herbicide treatments (Fig. 1a), although relative values for treatments varied among sample dates. Rotary hoeing and cultivation were effective in reducing weed numbers in all treatments. Discontinuities in lines in the figure reflect tillage operations between sample dates.

The number of weeds >2 cm (Fig. 1b) typically was greatest in late May and early June, with tillage, particularly cultivation, substantially reducing the number present.

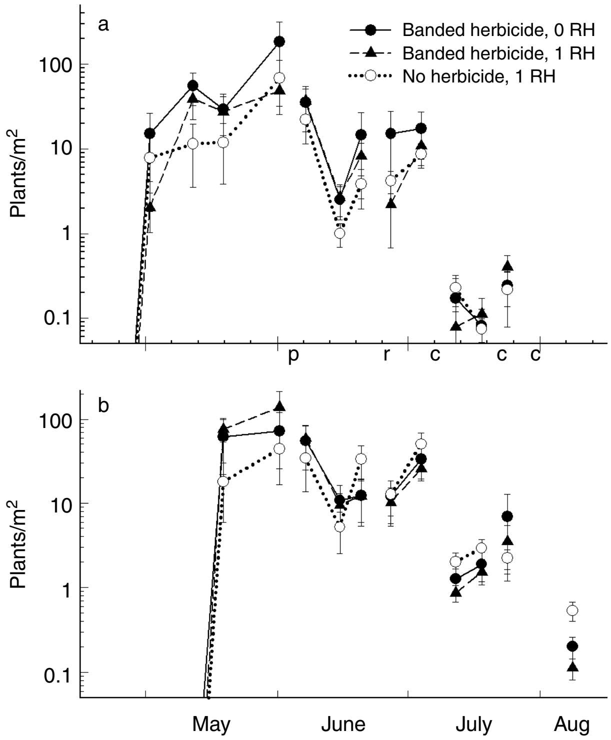

Figure 1. Mean total numbers of weeds (all species combined) present on plots with herbicide and no rotary hoeing (0 RH), with herbicide and one rotary hoeing (1 RH), or with no herbicide and one rotary hoeing at the Hartsock farm in 1990: (a) seedlings, (b) plants >2 cm tall. Bars indicate ± one standard error of the mean. Dates of field operations are indicated by letters (p, planting; r, rotary hoeing; c, cultivation). Data are plotted on log scales to accommodate extreme values.

Growth of plants previously categorized as seedlings also contributed to changes in number of weeds >2 cm after each tillage operation. Weeds >2 cm that were present late in the season arose almost entirely from seedlings appearing before the last cultivation, since practically no seedlings emerged after the last cultivation. In contrast, Forcella and Lindstrom[16] found that seed production from plants appearing after the last cultivation in a ridge-tillage system could contribute enough seeds to the soil seedbank to create substantial weed emergence the next year.

After all tillage operations were complete, weed populations in early August varied among farms in both years. Farms had a significant effect on foxtail species in both years and on Pennsylvania smartweed in 1990 (Table 5). Subsequently, values for the total over all species, a value dominated by foxtail species, and for the total over all broad-leaved species also showed a significant effect of farms in both years. Although there was substantial variation among farms in weed populations in both 1989 and 1990 (Tables 6 and 7), probably reflecting a combination of historical factors, spatial variation and unknown sources of variation, farm and herbicide treatment had no significant interaction in either year (Table 5). Over all farms, in 1989 herbicide treatment had a significant effect only for foxtail species and the total over all species (Table 5), and in 1990 herbicide/rotary hoeing treatment had a significant effect only for redroot pigweed (Table 5).

Since the experiments were conducted on commercial farms, no untreated, weedy plots were available for illustration of potential weed pressure on the sites. However, values of the highest number of weeds observed in June (e.g., 100–200 plants m^{-2} on the Hartsock farm, Fig. 1) imply that there were substantial weed densities and that the low values late in the season were due to successful control in all treatments, rather than lack of potential weeds. In 1989 (Table 6), tillage led to low numbers of total broad-leaved weeds and total weeds present on 1 August [<4600 ha^{-1} (<0.46 m^{-2}) total weeds on all farms]. In 1990 (Table 7), the total number of weeds was $<17{,}000$ ha^{-1} (<1.7 m^{-2}) on all farms. In both years, total broad-leaved weed populations in August were low [ranges of 382–2000 ha^{-1} (0.038–0.200 m^{-2}) in 1989 and 55–2900 ha^{-1} (0.0055–0.290 m^{-2}) in 1990]. These are within the range of the values of 0–1 m^{-2} often reported in the literature for good to excellent weed control[8,17–19], although the common practice of reporting weed numbers

Table 5. Analysis of variance results, over all farms, for numbers of weed plants on 1 August 1989 or 1 August 1990 and soybean yield in each year. Values are probability of a greater *F* value with an ANOVA model incorporating all the model terms listed (NS is given for $P > 0.05$). The totals over broad-leaved species and over all species include all species found, not just foxtail, smartweed and pigweed.

Model term	Foxtail species	Pennsylvania smartweed	Redroot pigweed	Total broad-leaved species	Total all species	Soybean yield
1989						
Farm	0.02	NS	NS	0.01	0.02	0.0001
Block (Farm)	NS	NS	NS	NS	NS	0.04
Herbicide treatment	0.005	NS	NS	NS	0.02	NS
Farm × herbicide treatment	NS	NS	NS	NS	NS	NS
1990						
Farm	< 0.0001	0.0001	NS	0.02	< 0.0001	0.0001
Block (Farm)	0.001	NS	NS	NS	0.002	0.0001
Herbicide/rotary hoeing treatment	NS	NS	0.03	NS	NS	NS
Farm × herbicide/rotary hoeing treatment	NS	NS	NS	NS	NS	NS

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Table 6. Weed populations on 1 August and soybean yield on three farms in Iowa in 1989.[1] All treatments also received rotary hoeing and cultivation (see Methods).

	Farm							
	Graaf		Grau		Hartsock		All farms	
	Mean	SE[2]	Mean	SE	Mean	SE	Mean	SE
Foxtail species (number ha^{-1})								
banded herbicide	902	373	217	99	829	291	649*	160
no herbicide	2510	805	658	255	3410	1000	2190*	480
Broad-leaved weeds (number ha^{-1})								
banded herbicide	1500	188	630	380	644	138	925	166
no herbicide	2000	609	382	228	1160	547	1180	300
Total weeds (number ha^{-1})								
banded herbicide	2400	443	847	371	1470	363	1570*	256
no herbicide	4510	1240	1040	373	4570	1480	3370*	719
Soybean yield (Mg ha^{-1})								
banded herbicide	2.20	0.064	3.04	0.016	2.39	0.026	2.54	0.168
no herbicide	2.32	0.054	2.98	0.019	2.44	0.028	2.57	0.138

[1] There was a significant effect of herbicide treatment, over all farms, for foxtail species and the total over all species.
[2] SE = standard error of the mean.

as integer values per m^2 makes comparisons particularly imprecise when values are less than 1 m^{-2}. It should also be recognized that the relationship between weed density and crop yield is variable with location, cropping system, etc.[20] None the less, a meaningful result here is that all treatments provided good to excellent weed control.

In 1989, soybean plant densities in mid-July were about 80% of the seeding density on all but the Graaf farm, where plant density was 53% of seeding density (Table 1). Over all farms, soybean yield in 1989 was significantly different among farms, but there was no significant difference between the banded herbicide and no herbicide treatments

Table 7. Weed populations on 1 August and soybean yield on three farms in Iowa in 1990.[1] All treatments also received cultivation (see Methods).

	Farm							
	Grau		Hartsock		Thompson		All farms	
	Mean	SE[2]	Mean	SE	Mean	SE	Mean	SE
Foxtail species (number ha^{-1})								
banded herbicide, 0 RH[3]	111	65	818	499	15,600	3900	5500	2124
banded herbicide, 1 RH	64	48	532	221	12,400	4610	4330	1240
no herbicide, 1 or 2 RH	3350	2020	3720	1660	9980	3480	5680	1490
Broad-leaved weeds (number ha^{-1})								
banded herbicide, 0 RH	440	434	1710	381	1290	429	1140	249
banded herbicide, 1 RH	55	38	1330	392	1670	801	1020	315
no herbicide, 1 or 2 RH	998	762	2900	1230	1660	713	1850	519
Total weeds (number ha^{-1})								
banded herbicide, 0 RH	551	438	2530	832	16,900	3910	6640	2130
banded herbicide, 1 RH	119	57	1860	587	14,100	5330	5360	2180
no herbicide, 1 or 2 RH	4350	2320	6620	1270	11,700	4100	7550	1620
Soybean yield (Mg ha^{-1})								
banded herbicide, 0 RH	2.67	0.147	2.07	0.008	2.97	0.093	2.57	0.206
banded herbicide, 1 RH	2.61	0.129	2.08	0.005	2.93	0.107	2.54	0.190
no herbicide, 1 or 2 RH	2.45	0.074	2.07	0.006	2.88	0.093	2.47	0.169

[1] There were no significant differences among herbicide treatments over all farms for mean values of any variable.
[2] SE = standard error of the mean.
[3] RH = rotary hoeing.

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(Tables 5, 6). In 1990, soybean plant densities in early August were 45–74% of the seeding densities (Table 2). Soybean yield in 1990 again was significantly different among farms but was not significantly different among herbicide/rotary hoeing treatments, over all farms (Tables 5, 7). Mean within-farm soybean yields were 2.26, 3.01 and 2.42 Mg ha^{-1} on the Graaf, Grau and Hartsock farms, respectively, in 1989 and 2.58, 2.07 and 2.93 Mg ha^{-1} on the Grau, Hartsock and Thompson farms, respectively, in 1990. Treatments within a farm (Tables 6, 7) differed from the respective within-farm mean by a maximum of 0.5% to 5% on the different farms, with no significant treatment effects on yield.

Weed control results and soybean yield of the various treatments in the 2 years together indicate that rotary hoeing plus cultivation can be an effective substitute for banded herbicide plus cultivation in a ridge-tillage system. Buhler et al.[8] found that rotary hoeing plus cultivation could largely replace herbicide, although control was not as good with higher weed populations. Although not directly tested here, timing of rotary hoeing is an important factor in determining its efficacy[21]. Rotary hoeing is most effective in destroying weed seedlings that have germinated but not emerged and is still highly effective on emerged seedlings less than 7 mm tall, with little root development[21,22]. Here, weed populations in May and June were reduced by rotary hoeing in both years, and many unemerged weed seedlings likely were also destroyed. Annual weed species with small seeds that germinate from depths <5 cm are better controlled by rotary hoeing than are larger-seeded species that may emerge from greater depths[23]. Results here are consistent with that observation in that the major weed species present are relatively small-seeded[24], typically have greatest emergence from depths of a few centimeters[25,26], and apparently were well-controlled by rotary hoeing followed by cultivation. Rotary hoeing and cultivation may lose effectiveness in those conservation tillage systems in which a considerable amount of residue remains on the surface during the tillage operations[27], but burial of residue during ridge-tillage planting minimizes this problem.

In summary, patterns of weed population dynamics were similar in 1989 and 1990. In both years, herbicide banded in the row at planting and treatments without herbicide all produced low numbers of weeds (especially of broad-leaved weeds) by August, with no significant difference in soybean yields, indicating that rotary hoeing plus cultivation were effective in replacing banded herbicide plus cultivation. Ridge-tillage can be effective in controlling weeds, and use of herbicide in ridge-tillage may be greatly reduced or even eliminated, thus reducing direct costs of herbicide application and potential environmental costs. However, such savings must be balanced against the costs and management demands of ridge-tillage. Furthermore, while ridge-tillage apparently has considerable potential as an alternative to herbicidal control of weeds, there remain questions as to how to optimize its efficiency. For example, the optimal timing, amount, direction, etc. of rotary hoeing need to be determined. Future research could address such questions, so that ridge-tillage can be optimized to balance degree of weed control, use of fossil fuels, management inputs and crop yield.

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