Assessment of Weed and Crop Fitness in Cover Crop Residues for Integrated Weed Management

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Assessment of weed and crop fitness in cover crop residues for integrated weed management

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Cover crop residues are not widely used for weed control because, as a stand-alone tactic, they do not effectively suppress all weeds and their duration of weed control is too short. Field experiments were conducted in 1995 and 1996, under both irrigated and rainfed conditions, to quantify *Amaranthus* spp., *Setaria* spp., and soybean emergence and growth in residues of fall-planted, spring-killed barley, rye, triticale, wheat, and hairy vetch. For both weed species, seedling emergence was reduced 3 wk after soybean planting by rye and wheat residues ($\geq$ 2,170 kg ha^{-1}) in 1996. In 1996, *Amaranthus* spp. canopy volume was reduced 38 to 71% by residues 3 wk after planting. Likewise, *Setaria* spp. canopy biomass was reduced 37 to 97% in residues 5 wk after planting over both years. The response comparison index was used to identify frequency by which weed growth was placed at a disadvantage relative to soybean growth. *Amaranthus* spp. and *Setaria* spp. growth suppressions 3 to 5 wk after planting indicate potential times for intervention with other integrated weed management tactics such as reduced postemergence herbicide rates and interrow cultivation.

Nomenclature: *Amaranthus* spp. AMASS; *Setaria* spp. SETSS; soybean, *Glycine max* (L.) Merr. 'Dunbar.'

Key words: Barley, hairy vetch, rye, triticale, wheat, germination, growth, relative fitness, nonchemical weed control, no-tillage, time of intervention, AMASS, SETSS.

Numerous authors have considered the role of cover crops a component of integrated weed management (Altieri and Liebman 1988; Liebman and Gallandt 1997; Swanton and Weise 1991). Integrated weed management is aimed at managing populations of weeds through a series of mortality- and fitness-reducing events. This can be accomplished with combinations of cultural, mechanical, biological, and chemical methods of weed control. The underlying premise of cover crops as a component of integrated weed management is that they exert a differential effect on weeds and the crop, resulting in decreased relative fitness of weeds.

Cover crop residues affect weed suppression. In the presence of barley (*Hordeum vulgare* L.), oats (*Avena sativa* L.), rye (*Secale cereale* L.), subterranean clover (*Trifolium subterraneum* L.), and wheat (*Triticum aestivum* L.) residues, weed biomass or density was reduced for the following species: barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.], common lambsquarters (*Chenopodium album* L.), common purslane (*Portulaca oleracea* L.), redroot pigweed (*Amaranthus retroflexus* L.), ryegrass (*Lolium perenne* L.), sicklepod [*Senna obtusifolia* (L.) Irwin and Barneby], and spiny amaranth (*Amaranthus spinosus* L.) (Brecke and Shilling 1996; Purvis et al. 1985; Putnam and DeFrank 1983).

Weed suppressive effects of cover crop residue decrease with time following cover crop residue decomposition. In 1 yr of an Ontario study, winter cereal residues reduced redroot pigweed density 63%, 5 wk after soybean planting, yet 1 to 3 wk later, densities were similar to the no-residue treatment (Moore et al. 1994). In Maine, Dyck and Liebman (1994) found that time to 50% emergence of common lambsquarters was delayed 3.4 d in the presence of soil-incorporated crimson clover residue. Additional studies indicate the greatest effect of rye residue on weed seedling emergence occurs shortly after killing the cover crop (Mohler and Callaway 1995). Redroot pigweed and common lambsquarters biomass in rye, wheat, and triticale residues was similar to the bare soil treatment in late September in Ontario soybean production, despite having significantly smaller biomass earlier in the season (Moore et al. 1994).

While cover crops may reduce weed fitness, they can adversely affect soybean stand establishment. Studies in Mississippi (Elmore et al. 1992) and Ontario (Wagner-Riddle et al. 1994) indicated wheat and rye residues, respectively, had no detrimental effect on soybean yield. Reduced yields in Ohio (Eckert 1988) and Illinois (Liebl et al. 1992) were primarily the result of poor seedling emergence in excessive rye residues due to insufficient soil/seed contact.

Traditionally, investigations of cover crops for weed suppression have involved their evaluation as a sole means of weed control. Regardless of the subsequent crop, many findings indicate additional weed management is necessary (Masiunas et al. 1995; Mohler and Teasdale 1993; Moore et al. 1994; Shilling et al. 1995; Teasdale and Mohler 1993). A gap currently exists between cover crop assessment for weed control in crop production and insight for integration with additional management tactics. In Midwestern soybean production, *Amaranthus* spp. and *Setaria* spp. are among the most common and most troublesome weeds (Bridges 1992). The objectives of this study were to quantify the influence of several cover crop residues on *Amaranthus* spp., *Setaria* spp., and soybean emergence and growth. A method to compare temporal differences between weed and crop response to residues is also discussed.

Materials and Methods

Site Description

Field experiments were conducted in the summers of 1995 and 1996 at the University of Nebraska Agricultural Research and Development Center near Ithaca, NE, on a Sharpsburg silty clay loam (fine, montmorillonitic, mesic, typic Argiudoll). Soil at the 1995 study site had 2.6% organic matter with pH 6.3, and soil at the 1996 site (3.8 km from the first location) had 2.8% organic matter and 5.8 pH. Both years, the previous crop was corn harvested for silage in early September.

At both sites, the following species were observed at low to moderate infestations: redroot pigweed, common waterhemp (*Amaranthus rudis* Sauer), velvetleaf (*Abutilon theophrasti* Medikus.), eastern blacknightshade (*Solanum ptycanthum* Dun. Ex DC.), yellow foxtail [*Setaria glauca* (L.) Beauv.], green foxtail [*Setaria viridus* (L.) Beauv.], and giant foxtail (*Setaria faberi* Herrm.). The spatial distribution of *Amaranthus* spp. seedlings was nonuniform at both locations. Since *Amaranthus* spp. and *Setaria* spp. were to be studied intensively, redroot pigweed and common waterhemp seeds were overseeded by hand on April 21, 1995, at 0.58 kg ha^{-1} (170 seeds m^{-2}). Because of lower than expected seedling emergence in 1995, the seeding rate was increased to 1.58 kg ha^{-1} (450 seeds m^{-2}) and seeded on October 20, 1995.

Experimental Design and Treatment Structure

The experimental design was a split-block design with three replications in fall 1994 and four in fall 1995. Each block consisted of vertical strips of a "cover" treatment factor and horizontal strips of a "water" treatment factor (horizontal strips orthogonal to vertical strips). The cover treatment factor had five treatment levels in fall 1994: (1) bare soil "control," (2) barley (cv. Perkins), (3) rye (cv. VNS), (4) triticale (*X Triticosecale* cv. Newcale), and (5) winter wheat (cv. Arapaho). A sixth treatment level, hairy vetch (*Vicia villosa* Roth), was added in fall 1995. The water treatment factor had two treatment levels: (1) rainfed, and (2) irrigated, with a sprinkler irrigation system assembled to irrigate one-half of each block. In irrigated plots, approximately 18 mm of water was applied weekly in June and July (Figure 1). Irrigation was not applied the week of June 17 or 24 because of uncommonly high precipitation during that time.

All cover crops were planted on September 7 in 1994 and 1995. In 1994, barley, rye, and wheat were no-till drilled at 78.4 kg ha^{-1} and triticale at 156.8 kg ha^{-1} at a depth of 2 cm on 25-cm rows in plots 31 by 4.6 m. In 1995, barley, rye, triticale, and wheat were drilled at a rate of 78.4 kg ha^{-1} and hairy vetch at a rate of 35.8 kg ha^{-1}.

Timing and rate of glyphosate application was based on cover crop growth stage. All cover crops were desiccated on June 6, 1995, with 2.2 kg ai ha^{-1} of glyphosate applied with a tractor-mounted compressed-air sprayer at 187 L ha^{-1}. On May 13, 1996, rye and triticale were sprayed with 1.1 kg glyphosate ai ha^{-1} using a hand-held CO_2-pressurized backpack sprayer delivering 187 L ha^{-1}. Remaining cover crops were allowed to grow an additional 10 d to compensate for delayed spring growth. On May 23, all plots were sprayed with 1.4 kg glyphosate ai ha^{-1} with a tractor-mounted compressed-air sprayer at 187 L ha^{-1}. Because hairy vetch was not completely controlled by the glyphosate application, remaining plants were clipped at the soil surface 3 wk after glyphosate was applied.

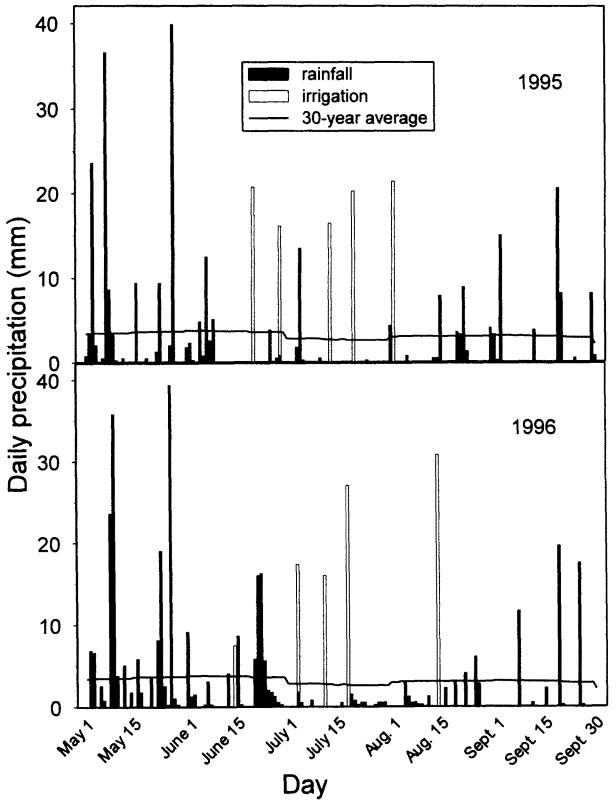

FIGURE 1. Daily rainfall and irrigation in 1995 and 1996.

On June 7, 1995, and May 21, 1996, Dunbar soybean (group III indeterminate) was no-till planted in 76-cm rows into standing cover crop residue to a depth of 2 cm at 250,000 seeds ha^{-1}. After the fifth week of *Setaria* spp. assessment, a mixture of 0.3 kg ha^{-1} of sethoxydim, 0.6 and 0.3 kg ha^{-1} of 28% urea ammonium nitrate, and petroleum-based crop oil concentrate[1] was applied by a tractor-mounted compressed-air sprayer at 187 L ha^{-1} on July 9, 1995, and July 2, 1996. A few other broadleaf weeds, including velvetleaf and eastern blacknightshade, were present in this study. Emergence of all broadleaf weeds was monitored through 7 wk after planting, then all broadleaf weeds other than *Amaranthus* spp. were hand removed from all plots.

Sampling and Analytical Procedures

To minimize misidentification of newly emerged seedlings, yellow foxtail, green foxtail, and giant foxtail were grouped as "*Setaria* spp.," while redroot pigweed and common waterhemp were pooled into the "*Amaranthus* spp." group. Within each subplot, emergence was monitored in two 0.38-m^2 permanent quadrats in 1995 and in six 0.38-m^2 quadrats in 1996. Individual seedlings were identified and counted on at least weekly intervals through 4 wk after planting (*Setaria* spp.) and 7 wk after planting (*Amaranthus* spp.).

Amaranthus spp. density was low in some plots, and to minimize altering the weed and crop community by removing plants, individual plants were measured nondestructive-

ly. Two weeks after crop planting, five *Amaranthus* spp. per subplot were identified for repeated, nondestructive canopy volume assessment. Measurements, taken at approximately 2-wk intervals, included height and canopy diameter. Height was measured from the soil surface to the top of the undisturbed plant, while canopy diameter was a single measure of average plant diameter. Individual plant canopy diameter was used to calculate plant canopy radius, which was then squared and multiplied by π to determine circular plant canopy area. Finally, *Amaranthus* spp. height and circular plant canopy area were combined to calculate cylindrical plant volume, a surrogate, nondestructive measure for biomass (Bussler et al. 1995).

Aboveground weed canopy size assessment, which combined weed density and individual size, was also taken within 3 wk (*Amaranthus* spp.) and 5 wk (*Setaria* spp.) of soybean planting. *Amaranthus* spp. canopy volume ($cm^3\ m^{-2}$) per subplot was determined by multiplying *Amaranthus* spp. volume ($cm^3\ plant^{-1}$) and *Amaranthus* spp. density (plants m^{-2}) for each subplot. In addition, three randomly selected *Setaria* spp. plants in each plot were clipped 1 cm above the soil surface, dried, and weighed. *Setaria* spp. canopy biomass ($g\ m^{-2}$) per subplot was determined by multiplying *Setaria* spp. biomass ($g\ plant^{-1}$) and *Setaria* spp. density (plants m^{-2}) in each subplot.

Microsite Conditions

Aboveground cover crop biomass was measured (oven dry) prior to glyphosate application by harvesting four 0.14-m^2 areas within each cover crop strip on June 5, 1995, May 8, 1996 (rye and triticale), and May 21, 1996 (barley, wheat, and vetch).

In 1995, soil moisture was measured on June 12, 18, and 27 and July 3, 12, and 28 by taking two 2.0-cm-diam cores per subplot with a hand-held probe to a depth of 15.2 cm, approximately 20 cm from the inner four soybean rows. Cores were divided into two 7.6-cm depths, and gravimetric soil water content (gravimetric soil water content [$g\ g^{-1}$] = g water in soil [wet^{wt} − oven dry^{wt}] g^{-1} oven-dry soil) was determined. Soil bulk densities at 0- to 7.6-cm and 7.6- to 15.2-cm depths were estimated to be 1.25 and 1.31 $g\ cm^{-3}$, respectively, for the experimental area in both locations (Williams II 1997). Based on the average soil bulk density across treatments, gravimetric soil water content was converted to volumetric soil water content (VSWC) (volumetric soil water content [$g\ cm^{-3}$] = gravimetric water content [$g\ g^{-1}$] · soil bulk density [$g\ cm^{-3}$]). Soil sampling was intensified in 1996, by taking 10 cores per subplot at three depths (0 to 7.6 cm, 7.6 to 15.2 cm, and 15.2 to 30.5 cm) on June 5 and 12 and July 10, 12, and 17. Soil bulk density from the 15.2- to 30.5-cm range was estimated at 1.33 $g\ cm^{-3}$. To relate soil water content to biological thresholds, we initially used laboratory-determined values of permanent wilting point (PWP) (1,500 kPa) and field capacity (30 kPa) for a nearby benchmark Sharpsburg silty clay loam soil. These values were later confirmed using composite soil samples taken from the experimental plots for which PWP and field capacity water contents were determined from soil bulk density, sand silt and clay, and carbon contents as described by Gupta and Larson (1979). Volumetric soil water content at 60% water-filled pore space (WFPS) was 31.7, 30.3, and 29.9% at 0- to 7.6-, 7.6- to 15.2-, and 15.2- to 30.5-cm soil depth intervals, respectively, where WFPS = VSWC ÷ soil porosity and soil porosity = (1 − soil bulk density ÷ 2.65).

Soil maximum-minimum thermometers were used to monitor temperature fluctuations 1.3 cm deep in soil. Maximum and minimum temperatures were recorded during emergence counts (every 3 to 7 d), and thermometers were reset. In 1995, thermometers were placed in all subplots, but due to instrumentation constraints in 1996, thermometers were only placed in rye, vetch, and control subplots. Mean temperature was calculated from maximum and minimum temperatures.

Crop and Weed Response Comparisons

To assess the relative effects of cover crop residues on weeds and soybean, absolute competition intensity (ACI) was adapted to measure relative fitness (Grace 1995). The relative response index (RRI) expresses plant response to cover crop residues in relation to the bare soil control, standardizing individual species response to cover crop residues. The relative response index is calculated as:

$$RRI = (P_{cn} - P_r)/(P_{cn} + P_r) \quad [1]$$

where P_{cn} represents plant response (e.g., density, size, or grain yield) in the bare soil control and P_r is plant response in a residue environment. Therefore, an RRI value more than 0 indicates residues decreased plant fitness; an RRI value equal to 0 indicates residues had no effect; and an RRI value less than 0 indicates cover crop residues increased plant fitness.

The response comparison index (RCI) quantifies the difference between relative responses of two species, where:

$$RCI = RRI_W - RRI_C \quad [2]$$

RRI_W is the RRI of a weed (e.g., *Amaranthus* spp.), and RRI_C represents that of the crop (e.g., soybean). Thus, when RCI is more than 0, the relative fitness of the crop is greater than the weed. When RCI is less than 0, the relative fitness of the weed is enhanced. If weed and crop responses vary through time, as they did in these studies, analysis of periodic RCI values can detect temporal changes in relative weed and crop fitness. This approach provides an analytical basis for identifying when the crop is no longer at a competitive advantage over the weed, and additional weed suppression may be needed (RCI $\leq$ 0).

Relative response indices of emergence and size were independently calculated for *Amaranthus* spp., *Setaria* spp., and soybean within each replicate and water level. For size comparisons of *Setaria* spp. and soybean RRI values in 1995, dry biomass ($g\ plant^{-1}$) of three randomly selected plants per plot, of both species, was analyzed. However, in 1996, the RRI values of soybean volume ($cm^3\ plant^{-1}$) of three plants per plot were compared to the RRI value for *Setaria* spp. biomass ($g\ plant^{-1}$) of three individuals. For size comparisons of *Amaranthus* spp. and soybean RRI values in 1995, plant volumes ($cm^3\ plant^{-1}$) of five plants per plot, flagged 2 wk after planting and measured throughout the course of the season, were compared. The same approach was taken in 1996; however, only three soybean plants per plot were measured.

TABLE 1. Cover crop biomass at the time of desiccation in 1995 and 1996.

Cover	Kill date[a]	
	June 6, 1995	May 23, 1996
	kg ha^{-1}	
Barley	3,170 b	130 d
Rye	6,310 a	2,890 a[b]
Triticale	7,160 a	750 c[b]
Wheat	6,710 a	2,170 b
Vetch	—	650 c

[a] Means within a column followed by the same letter are not significantly different at 0.05 level as determined by Fisher's Protected LSD test.
[b] Kill date of May 13, 1996.

Statistical Analysis

Analysis of variance was conducted on cover crop biomass, weed seedling emergence and growth, and crop and weed response comparisons (SAS 1995). Main effects and interactions were examined, and treatment comparisons were made with Fisher's Protected LSD test at the 95% confidence level. Because there were significant year by treatment effect interactions, data were not pooled over years.

Because data from each year were analyzed separately, hairy vetch residue was included as a treatment level in 1996. Consequently, cover crop biomass data were analyzed as a randomized complete block with four treatment levels in 1995 and five treatment levels in 1996. Data for canopy size (biomass or volume) 21 to 35 DAP were analyzed as a split block. Seedling emergence data and RCI values of emergence and growth data were analyzed as a split block with time as unstructured repeated measures.

Results and Discussion

Cover crop biomass production in 1995 was two to 25 times that observed in 1996 (Table 1). Equipment constraints, coupled with cool temperatures and abundant spring rainfall (Figure 1), delayed the cover crop kill date until June 6 in 1995. Physiologically, all winter cereals reached full flowering, and dry cover crop biomass ranged from 3,170 to 7,160 kg ha^{-1}. In 1996, cover crop growth varied greatly. For instance, barley had less than 10% survival, resulting in 130 kg ha^{-1} of biomass, whereas rye produced 2,890 kg ha^{-1} dry matter by May 13. Rye and wheat consistently produced the greatest cover crop biomass.

Amaranthus spp. Emergence

In 1995, *Amaranthus* spp. emergence was less than one plant m^{-2} across all treatments through 28 d after soybean planting (DAP); consequently, it was difficult to detect treatment effects at this time. An increased seeding rate the following year, coupled with seed exposure to overwintering conditions, resulted in higher overall emergence in 1996. Relative to the control, wheat delayed *Amaranthus* spp. seedling emergence through 21 DAP (Figure 2). Although not statistically significant (at P = 0.05), rye and hairy vetch numerically reduced weed density through 20 DAP. Barley, which had only 130 kg ha^{-1} of biomass, resulted in emergence patterns nearly identical to the control. Redroot pigweed emergence is favored by soil temperatures between 18

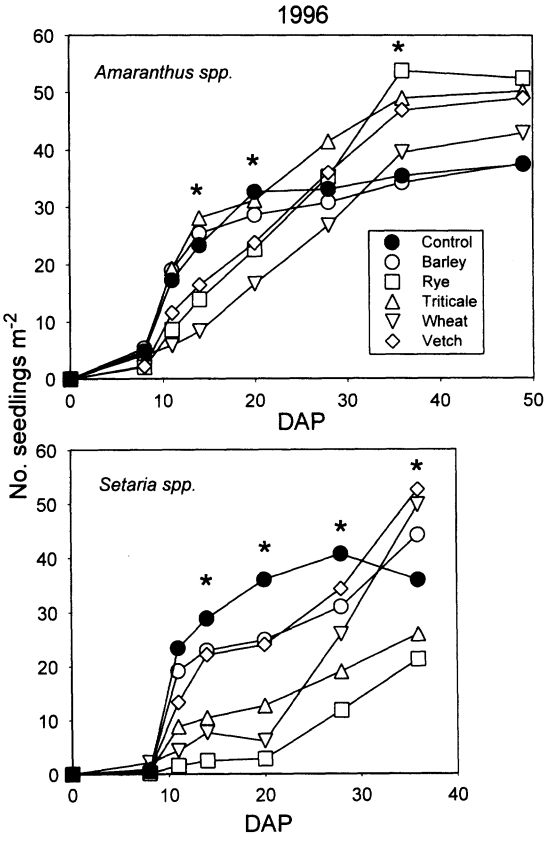

FIGURE 2. *Amaranthus* spp. and *Setaria* spp. emergence in 1996. Protected LSD differences in cover treatment levels for given sampling period are indicated by an *.

and 27 C (Wiese and Davis 1967). Because mean soil temperature in the control treatment was warmer than rye residue through 36 DAP (Figure 3A), it is plausible that optimal temperatures for emergence were reached more quickly in the absence of cover crop residues. Delayed emergence of *Amaranthus* spp. due to residue presence has been observed in other field studies (Mohler and Callaway 1995; Moore et al. 1994).

Amaranthus spp. density increased 36 DAP in rye residue. Others have observed this phenomenon with sicklepod and attributed this effect to soil disturbance or possibly improved moisture conditions for seedling emergence under the residue (Mohler and Teasdale 1993; Shilling et al. 1995). In this study, soil was not disturbed. However, shortly after precipitation events, our visual observations indicated higher soil water content at the soil surface under residue treatments. This would suggest cover crop residues may extend the duration of seedling emergence when soil moisture drops below thresholds for seedling emergence in nonresidue areas. However, late emerging *Amaranthus* spp. may not have caused additional yield loss. Dieleman et al. (1995) found time of weed emergence more important than weed density when describing the effect of *Amaranthus* spp. on soybean yield. In their study, Powell amaranth (*Amaranthus powellii* S. Wats.) and redroot pigweed emerging at the V2 stage of soybean remained small and noncompetitive. In our study, soybean was at the V2 stage 28 DAP and at V3, 36 DAP, and was large enough to outcompete *Amaranthus* spp. emerging beyond 28 DAP.

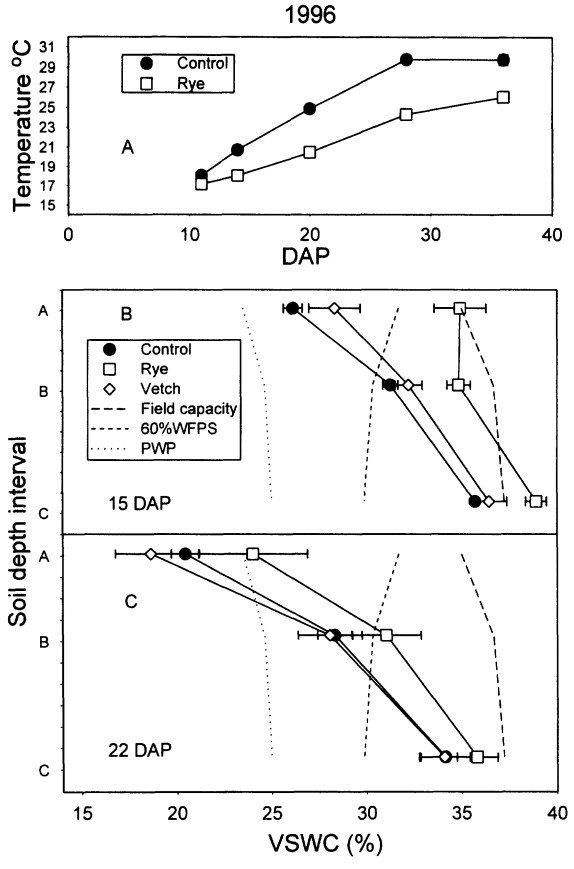

FIGURE 3. (A) Mean soil temperature 1.3 cm deep in 1996. (B) VSWC 15 DAP in 1996. (C) VSWC 22 DAP in 1996. Bulk density, averaged over treatments, was 1.25 (±0.05), 1.31 (±0.05), and 1.33 (±0.05) g cm^{-3} at soil depth intervals A (0 to 7.6 cm), B (7.6 to 15.2 cm), and C (15.2 to 30.4 cm). Permanent wilting point (1,500 kPa) and field capacity (30 kPa) are for a benchmark Sharpsburg soil. Standard error bars are presented.

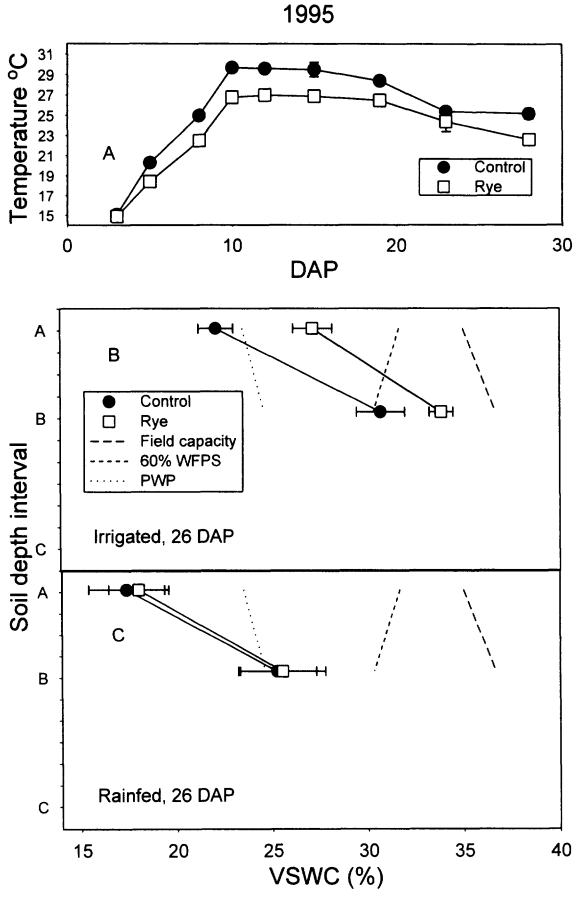

FIGURE 4. (A) Mean soil temperature 1.3 cm deep in 1995. (B) VSWC 26 DAP in irrigated treatment. (C) VSWC 26 DAP in rainfed treatment. Bulk density, averaged over treatments, was 1.25 (±0.05) and 1.31 (±0.05) g cm^{-3} at soil depth intervals A (0 to 7.6 cm) and B (7.6 to 15.2 cm). Permanent wilting point (1,500 kPa) and field capacity (30 kPa) are for a benchmark Sharpsburg soil. Standard error bars are presented.

Setaria spp. Emergence

Cover crop residues had a very different effect on *Setaria* spp. emergence between 1995 and 1996. In the first year, differences in seedling densities in cover treatment levels were not detected, although the irrigated treatment increased *Setaria* spp. seedling emergence 19 DAP (data not presented). Although nonsignificant, rye and wheat residues appeared to have higher densities of *Setaria* spp. After planting, soil moisture was lower than normal due to lack of rainfall, and there may have been more favorable microsites for seedling emergence and survival in high residue plots (Figures 4B and 4C). Increasing the sampling area in 1996, as well as an additional replication in the experimental design, may have provided greater precision for detecting population differences between cover crop treatments. Wheat residue reduced seedling emergence 20 DAP, while rye reduced emergence through 28 DAP (Figure 2). The presence of triticale delayed *Setaria* spp. emergence, although barley and vetch only numerically reduced *Setaria* spp. density through 28 DAP. Like *Amaranthus* spp. emergence, *Setaria* spp. densities in cover crop treatments were comparable to the control by 36 DAP. Masiunas et al. (1995) observed reduced giant foxtail density several weeks after desiccation of rye with glyphosate, relative to a conventionally tilled treatment without the cover crop in Illinois, Indiana, and Kentucky.

The amount of cover crop residue is a significant factor influencing outcomes in weed emergence. In New York and Maryland, Mohler and Teasdale (1993) found it took two to four times the typical cover crop biomass to reduce total whole-season weed seedling emergence for many species. Residue rates, comparable to ours, delayed emergence of redroot pigweed, reduced yellow foxtail seedlings, and decreased green foxtail densities in 1 of 2 yr. Although field rates of cover crop residues do not provide consistent emergence suppression, they can postpone seedling emergence several weeks.

Amaranthus spp. Growth

A critical minimum residue biomass, regardless of cover crop species, was necessary to significantly suppress initial individual *Amaranthus* spp. size. Any residue treatment with greater than 750 kg ha^{-1} aboveground biomass reduced *Amaranthus* spp. volume 36 to 89% through 42 DAP (data not presented). Apparently, when presence of a cover crop residue decreased *Amaranthus* spp. growth, suppression was greatest early in plant development.

Rye, wheat, and vetch residues reduced *Amaranthus* spp. canopy volume 71, 58, and 67%, respectively (Table 2). Here, reduced *Amaranthus* spp. emergence and seedling

TABLE 2. Effects of cover and water on early season (21 to 35 DAP) plant canopy size.[a]

	Amaranthus spp. canopy volume		*Setaria* spp. canapy biomass	
	1995[b]	1996[c]	1995	1996
	$cm^3\ m^{-2}$		$g\ m^{-2}$	
Cover				
Control	—	179.2 a	68.0 a	21.4 a
Barley	—	111.1 ab	27.6 b	13.4 ab
Rye	—	51.4 b	30.9 b	0.7 b
Triticale	—	92.6 ab	32.1 b	9.6 a
Wheat	—	74.5 b	14.6 b	3.5 b
Vetch	—	59.1 b	—	8.7 b
Water				
Irrigated	—	100.4	63.4	9.4
Rainfed	—	88.9	5.9	9.7
		NS	S	NS

[a] Means within a column followed by the same letter are not significantly different at the 0.05 level as determined by Fisher's Protected LSD test.
[b] Insufficient early season *Amaranthus* spp. emergence.
[c] Cover factor for *Amaranthus* spp. in 1996 is significant at the 0.1 level; all other factors are significant at the 0.05 level.

growth with cover crop residues resulted in large differences in *Amaranthus* spp. canopy size 21 DAP.

Setaria spp. Growth

Setaria spp. aboveground canopy biomass was reduced by the presence of cover crop residues. While not significant, *Setaria* spp. densities were numerically higher in rye, triticale, and wheat residues in 1995. However, the seedling fitness was significantly reduced. All residues reduced seedling growth ($g\ m^{-2}$) 53 to 79% (Table 2). While differences in *Setaria* spp. density were observed earlier in 1996, late emerging seedlings in cover crop residues resulted in similar densities 38 DAP. Yet, because of reduced seedling growth, canopy biomass in residues ranged from 3% (rye) to 52% (barley) of the bare soil treatment. Therefore, although the residues we investigated did not have a consistent effect on *Setaria* spp. emergence, they did delay seedling growth and result in a lower weed biomass at approximately 35 DAP in both years.

Soil water content at or near the surface may help explain differences in *Amaranthus* spp. and *Setaria* spp. infestations early in the season. A review by Doran and Linn (1994) found that, in several cases, chemical or microbial transformations of cover crop exudates resulting in phytotoxic compounds are favored under cool, wet anaerobic conditions. Aerobic microbial activity increases from a 30% WFPS to a maximum near 60% WFPS (Linn and Doran 1984). Oxygen becomes limiting at greater WFPS, and anaerobic activity increases beyond 80% WFPS. Furthermore, under oxygen-limiting conditions, organic acids are produced. An example of this process is the fermentation of wheat straw under cool, wet conditions. A by-product of the fermentation is acetic acid, a potent seedling growth inhibitor (Lynch 1977).

Fifteen days after planting in 1996, the bare soil treatment maintained soil moisture conditions well within the bounds of aerobic microbial activity (Figure 3B). On the contrary, the presence of rye residue resulted in a WFPS (66.1% at a 0- to 7.6-cm depth) near the threshold of anaerobic microbial activity. Even 22 DAP, rye residues maintained a greater VSWC at the 0- to 7.6-cm depth (Figure 3C). Similar soil moisture conditions for residues were observed in 1995. Taking into account frequent irrigation and natural precipitation, it is possible that the highest residue levels enhanced conditions favoring anaerobic microbial activity several weeks after cover crop desiccation. Consequently, *Amaranthus* spp. and *Setaria* spp. density and canopy size may have been reduced in cover crop residues through the combination of allelopathic leachates and transformation of leachates to compounds inhibitory to seedling development.

Emergence Comparisons

Soybean had a competitive advantage over *Amaranthus* spp. in wheat and rye residues early in 1996. Fourteen and 20 DAP, relative crop emergence was greater than the weed (Table 3). Presence of wheat residue from 2 to 3 wk after planting decreased weed density 57% while limiting soybean emergence 19% (Williams II 1997). Likewise, presence of rye residue 11 DAP resulted in reduced *Amaranthus* spp. density relative to soybean. Due to poor *Amaranthus* spp. emergence in 1995, RCI values of *Amaranthus* spp. and soybean seedling emergence could not be calculated.

Cover crop biomass production was extremely high in 1995. Rye, triticale, and wheat produced 6,310 to 7,160 $kg\ ha^{-1}$, three times the typical rate, and resulted in detrimental effects on the crop and weed. Excessive rye, triticale, and wheat residue interfered with soybean seed placement and reduced overall density 53 to 64% (Williams II 1997). Since differences in *Setaria* spp. density were not detected, RCI of the two species indicated crop emergence was placed at a significant disadvantage (Table 3). Irrigation 19 and 23 DAP also placed the crop at a disadvantage, due to detrimental lack of soil moisture for weed emergence in the rainfed treatment. In contrast, in 1996, rye residues resulted in a higher RCI for the crop than *Setaria* spp. This is due to 92% suppression of *Setaria* spp. emergence through 20 DAP and minimal reduction of soybean emergence. Though not statistically significant, the presence of triticale and wheat residues favored soybean emergence through 4 wk after planting, and at no time did residues favor *Setaria* spp. emergence. While soybean planting is limited by excessive cover crop biomass, typical field rates of residue can favor soybean seedling emergence over weed emergence.

Size Comparisons

The relative fitness of soybean increased in the presence of cover crop residues. In 1 of 2 yr, the presence of rye, triticale, and wheat significantly reduced relative *Amaranthus* spp. fitness as evidenced by the positive RCI values (Table 4). For instance, *Amaranthus* spp. volume was reduced 85% in the presence of wheat residue through 4 wk after planting in 1995. Rye and triticale had similar effects on crop and *Amaranthus* spp. response. Both years, *Setaria* spp. biomass was placed at a disadvantage by cover crop residues (Table 4). Early season *Setaria* spp. biomass in residues of rye and wheat averaged 9% of the control in 1996. Similar findings for all residues were found the first year of the study. For

TABLE 3. The response comparison index (RCI) for relative weed and soybean emergence.

	Weed and crop emergence comparison[a] RCI[b]												
	Amaranthus spp. and soybean								*Setaria* spp. and soybean				
	1995[c]	1996				1995			1996				
		11 DAP	14 DAP	20 DAP	28 DAP	36 DAP	19 DAP	23 DAP	28 DAP	11 DAP	14 DAP	20 DAP	28 DAP	36 DAP
Cover														
Barley	—	0.11	0.04	0.09	0.01	0.00	−0.28	−0.28	−0.20	0.02	−0.11	−0.13	−0.03	−0.18
Rye	—	0.41*	0.25	0.19	−0.07	−0.24	−0.76*	−0.68*	−0.65*	0.71*	0.71*	0.69*	0.33	0.16
Triticale	—	−0.02	0.02	−0.01	−0.11	−0.17	−0.77*	−0.70*	−0.72*	0.29	0.25	0.27	0.16	0.11
Wheat	—	0.16	0.46*	0.41*	0.12	−0.01	−0.52	−0.56*	−0.46	0.20	0.23	0.39	0.09	−0.06
Vetch	—	−0.04	0.11	0.13	−0.13	−0.24	—	—	—	−0.02	0.10	0.08	−0.02	−0.12
Water														
Irrigated	—	0.17	0.20	0.21	0.02	−0.11	−0.75*	−0.73*	−0.56	0.22	0.29	0.28	0.11	−0.03
Rainfed	—	0.08	0.15	0.12	−0.09	−0.15	−0.41	−0.38	−0.45	0.26	0.19	0.24	0.11	−0.00

[a] Significant difference from zero at the 0.05 level is indicated by an *.
[b] Where RCI > 0, the relative emergence of soybean is greater than the weed; where RCI < 0, the relative emergence of the weed is greater than soybean.
[c] Insufficient early season *Amaranthus* spp. emergence.

TABLE 4. The response comparison index (RCI) for relative weed and soybean size.

	Weed and crop size comparison[a] RCI[b]														
	Amaranthus spp. and soybean										*Setaria* spp. and soybean				
	1995				1996						1995			1996	
	22 DAP	29 DAP	50 DAP	69 DAP	21 DAP	29 DAP	37 DAP	48 DAP	63 DAP	79 DAP	14 DAP	22 DAP	34 DAP	29 DAP	37 DAP
Cover															
Barley	0.36	0.38	0.39	0.31	−0.19	−0.20	−0.20	−0.09	0.10	0.13	0.42*	0.37*	0.20	0.12	0.15
Rye	0.11	0.48*	0.34	0.38	0.03	0.10	0.16	−0.07	0.22	0.40*	0.58*	0.40*	0.34*	0.39*	0.44*
Triticale	0.50*	0.50*	0.01	−0.01	−0.04	0.13	0.08	−0.11	0.11	0.27	0.43*	0.37*	0.40*	−0.14	0.15
Wheat	0.64*	0.50*	0.17	0.20	−0.08	0.17	0.07	−0.13	−0.06	−0.02	0.49*	0.53*	0.33*	0.35*	0.29*
Vetch	—	—	—	—	−0.07	0.25	0.18	0.07	0.29	0.41*	—	—	—	0.19	0.41*
Water															
Irrigated	0.55	0.78*	0.28	0.30	0.03	0.17	0.08	−0.19	−0.04	0.00	0.47*	0.47*	0.56*	0.29*	0.27*
Rainfed	0.25	0.14	0.17	0.14	−0.17	0.01	0.04	0.06	0.31*	0.48*	0.49*	0.37*	0.08	0.07	0.31*

[a] Significant difference from zero at the 0.05 level is indicated by an *.
[b] Where RCI > 0, the relative size of soybean is greater than the weed; where RCI < 0, the relative size of the weed is greater than soybean.

nearly every cover crop residue and time period, soybean growth was favored to some degree over *Setaria* spp. growth.

At no time did irrigated or rainfed conditions favor weed growth over soybean growth in cover crop residues. For nearly all sampling dates, averaged over all cover crop residues, *Setaria* spp. growth was consistently suppressed relative to the crop in both moisture treatments as supported by positive RCI values (Table 4). *Amaranthus* spp. growth was reduced relative to soybean growth in both irrigated and rainfed conditions, but no obvious pattern was apparent between years. Despite striking differences in precipitation and soil moisture in the 2 yr of this study, soybean growth was never placed at a disadvantage in cover crop residues and frequently exceeded that of the weed.

The RCI method identifies when the crop is placed at a competitive advantage over the weed. Our field data support the idea that cover crop residues can selectively regulate plant emergence and growth, often times favoring soybean over *Amaranthus* spp. and *Setaria* spp. In addition, this advantageous competitive shift generally occurs shortly after cover crop desiccation and soybean planting.

Although final *Amaranthus* spp. and *Setaria* spp. seedlings generally exceeded threshold densities (Dieleman et al. 1996; Knake and Slife 1962), the decreased relative weed fitness from cover crop residues, as well as the lower infestation level 3 to 5 wk after planting, has significant value in an integrated weed management system. For instance, effectiveness of a postemergence herbicide depends largely on weed growth stage and size. Studies indicate dosages below recommended rates are effective when either a low weed density exists or the plants are small (DeFelice et al. 1989; King and Oliver 1992; Klingaman et al. 1992). A lower weed infestation, either by fewer individuals, smaller individuals, or both, increases efficacy of reduced rates of postemergence herbicides. Other integrated weed management tactics that capitalize on lower weed infestations and weed fitness shortly after crop planting include mechanical tillage, competitive crop cultivars, crop row spacing, and biological control agents.

Source of Materials

[1] Crop oil concentrate, Farmland Industries, Inc., 3315 North Oak Trafficway, Kansas City, MO 64116-0005.

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