Integrated Weed Management Strategies as Alternatives to Atrazine

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PROBLEM ADDRESSED

Atrazine is a standard for weed control in corn on the sandy soils of the Southeastern Coastal Plains. Because of the low clay and organic matter content of these soils, atrazine can readily move off site and potentially contaminate water resources in this region. Weed management systems that supply at least equivalent, economical, acceptable weed control are needed. Integration of cover crops, conservation tillage, and narrow row widths with herbicide-resistant hybrids may replace standard practices that rely heavily on conventional tillage, wide rows, and atrazine plus *S*-metolachlor.

OBJECTIVES

1) Develop effective alternative weed management strategies that will reduce grower reliance on atrazine.
2) Define the critical period of weed management in narrow- and wide-row corn.

METHODOLOGY

Objective 1: Alternative weed management systems - Experiment #1.

A field study was conducted at the Edisto Research and Education Center near Blackville, SC to assess the potential for using small grain cover crops and glyphosate as a means of reducing or eliminating the need for atrazine in Southeastern corn production. Cover crop treatments were 1) oats, 2) rye, 3) wheat, and 4) none (bareground) with the small grains seeded in strips across the test site. Cover crops were randomized within each replication. 'Coker 820' oats , 'Wrenz' rye, and 'Pioneer 2684' wheat were no-till, drill during the fall and subsequently killed with glyphosate in spring two weeks prior to planting corn. A bareground, conventional tilled system was included for comparison. 'Dekalb 662 RR' corn (glyphosate resistant) was strip-till planted in small grain plots and conventionally seeded in the bareground, conventional tilled treatments. Strip tillage for each row consisted of two wavy coulters, an in-row subsoil shank, and a roller-conditioner for seedbed preparation producing a narrow tillage stip in which corn was seeded. All plots were seeded at 69,000 seed/ha in 97-cm-wide rows. Herbicide programs evaluated within each cover crop and bareground, conventional tilled plot included: 1) nontreated; 2) 1.68 kg ai/ha atrazine plus 1.08 kg ai/ha *S*-metolachlor at planting followed by 0.84 kg/ha glyphosate at 76-cm tall corn; and 3) a total POST program of 0.84 kg/ha glyphosate at 56-cm height corn followed by 0.84 kg/ha glyphosate at 76-cm height corn. A standard atrazine-based system was evaluated only in bareground, conventional tilled plots. The standard system was comprised of 1.68 kg/ha atrazine plus 1.08 kg/ha *S*-metolachlor at planting followed by 1.12 kg/ha atrazine plus 1% v/v crop oil concentrate at 31-cm height corn.

Pitted morningglory, entireleaf morningglory, Palmer amaranth, Florida pusley, large crabgrass, and common bermudagrass infested the plot area the first year, whereas pitted morningglory, entireleaf morningglory, Florida pusley, and Palmer amaranth were present the subsequent year. Control of each species was visually rated 3 and 12 wk after corn emergence (WAE). Corn density in 1 m of row and height of 3 randomly selected plants were determined 3 and 7 WAE. On the same day, corn and weed biomass by species were harvested from 1 m^2 quadrats, oven-dried, and weighed.

Corn grain was machine harvested from the two center rows of each plot at maturity and seed moisture adjusted to 15.5%. The 2002 Clemson University Corn Enterprise Budgets were used to calculate variable cost and gross return (Anonymous 2002a). Variable cost included field preparation, cover crop and corn seed, planting, herbicide and application, and labor. Herbicide and seed costs from the Clemson University Corn Enterprise Budgets are averages taken from local suppliers. Seed costs for a conventional hybrid were used for treatments not receiving an in-crop glyphosate application. Cost of irrigation was not included because all experimental treatments were irrigated similarly. Because all plots received glyphosate for dessication of small grain or existing weeds, this cost was not included; thus, herbicide costs are only in-crop applications for corn. However, conventional tillage system normally do not receive glyphosate prior to disking; thus, use of glyphosate for cover crop dessication would be an added expense compared to a conventional tillage system. Gross return was the product of grain yield and a 2002 enterprise budget price of 9.67 cents per kg of grain. Gross profit margin was calculated by subtracting variable cost from gross return.

Objective 1: Alternative weed management systems - Experiment #2.

A field study was conducted at the Pee Dee Research and Education Center near Florence, SC to assess the potential for using small grain cover crops, narrow rows, conservation tillage, and glyphosate as a replacement for atrazine plus *S*-metolachlor in Southeastern corn production. The experimental design was a randomized complete block with four replications. Experimental treatments included all combinations of surface tillage (tilled or none), row widths (38 or 76 cm), and herbicide programs (atrazine at 1.68 kg/ha plus *S*-metolachlor at 1.68 kg/ha applied preemergence; glyphosate at 0.84 kg/ha applied at the V6 to V7 corn growth stage; or no herbicide) without a cover crop. Additional treatments included all combinations of cover crops (wheat or rye), row widths (38 or 76 cm), and herbicide programs (glyphosate at 0.84 kg/ha applied at the V6 to V7 corn growth stage or no herbicide) all without surface tillage for a total of 20 experimental treatments. Atrazine plus *S*-metolachlor was not applied in conjunction with cover crops because the preemergence herbicides would mask any weed suppression from the cover crop. Plots assigned to be surface tilled were disked twice to a depth of 18 cm then the entire test area was broadcast deep tilled to a 41-cm depth using a four-shanked ParaTill equipped with a serrated cutting coulter mounted in front of each shank. ‘Asgrow 687 RR’ corn (glyphosate resistant) was planted at 59,000 seed/ha in 38 and 76 cm width rows on April 9, 2002 and April 22, 2003. Wide- and narrow-row plots consisted of six and twelve 9 m rows, respectively. Glyphosate at 0.84 kg/ha was applied to all plots not having surface tillage, including the no herbicide treatments (in-crop), on the same day in which corn was planted to control the cover crops and winter weeds. Plots were visually rated for weed control by species prior to the in-crop glyphosate application (only 2003) and again 15 wk after corn emergence (WAE) on a scale of 0 to 100, with 0 = no control and 100 = complete control. Early-season corn injury was rated prior to the in-crop glyphosate application, with 0 = no injury and 100 = crop death. At 15 WAE, above-ground weed biomass was harvested from a 1 m^2 quadrat in each plot, oven-dried, and weighed. At maturity, corn was hand harvested in 2002 and subsequently thrashed to determine grain yield, whereas grain was machine harvested in 2003. Yields were corrected to 15.5% moisture.

Objective 2: Critical period for weed control.

Field experiments were conducted at the Edisto Research and Education Center near Blackville, SC, in 2002 and 2003, and at the Simpson Station near Pendleton, SC in 2003. All fields were harrowed twice and field cultivated at least once prior to planting corn both years. Trials were established as a randomized complete block with a split-plot design with row spacing as the main plot and weed infestation duration or weed-free period as subplots. Weed removal timings were based on weeks after corn emergence. Increasing duration of weed interference treatments allowed weeds to compete with corn from planting through 1, 2, 3, 4, 5, 6, 9, and 10 wks after corn emergence, except at Blackville in 2002 when weeds were removed at 8 rather than 9 wks after corn emergence. To determine the critical weed-free period, plots were kept weed-free for 1, 2, 3, 4, 5, 6, 9, and 10 wks after corn emergence, except an 8 wk weed-free period was used in 2002, rather than nine. Additionally, season-long weed-free and weedy treatments were included. Weeds were removed by hand hoeing weekly throughout the season. Although the corn was glyphosate resistant, no herbicides were used for weed control throughout the study.

Aboveground weed biomass was harvested from a 0.5 m^2 quadrat in weed-free period plots prior to grain harvest. Harvested biomass was oven-dried, and then weighed. Corn grain was machine harvested from the two center rows of wide-row plots and four center rows of narrow-row plots in 2002. In 2003, corn was hand harvested from a single row in the center of each plot and subsequently thrashed to determine grain yield. Actual and relative yield data were subjected to ANOVA using the PROC MIXED function of SAS to assess the effect of weed-free period and weed interference duration on actual and relative corn yields. Nonlinear regression analysis using the PROC NLMIXED function of SAS was used to evaluate the response of relative corn yields to increases in length of the weed-free period or weed interference duration in both row widths using days after corn emergence (DAE) as the independent variable. Equation 1 was used to determine the effect of the weed-free period (weed control duration) on relative grain yield:

$$Y = a \times \exp(- b \times \exp(- k \times T)) \qquad [1]$$

where Y is the relative yield (% of season-long weed-free yield), a is the yield asymptote, b and k are constants, and T is the number of days after corn emergence. Equation 2 was fitted to assess the effect of weed interference duration on relative yield:

$$Y = [(1/\{\exp[c \times (T - d)] + f\}) + [((f - 1) / f]] \times 100 \qquad [2]$$

where Y is the relative yield (% of season-long weed-free yield), T is the number of days after corn emergence, d is the inflection point (days), and c and f are constants. Differences in parameter estimates between row widths were tested to determine if regressions were nonparallel. If any parameter was different between row widths, separate regressions were fitted for each row width, whereas if all parameters were similar between row widths, a single regression was deemed appropriate. The critical period of weed control was determined assuming acceptable yield loss of 5%.

Equation 2 was fitted to characterize the progression of light interception following corn emergence with the response variable and upper asymptote reflecting percentage light interception rather than relative yield. Equation 3 was used to describe the effect of weed-free period on end-of-season weed biomass:

$$Y = a / (1 + \exp(b \times (T - c))) \qquad [3]$$

where Y is weed biomass (g/m^2), a is the range between the maximum and minimum biomass production, b is the slope of the curve at the greatest point of inflection, c is the point of greatest inflection (days), and T is the number of days after crop emergence.

RESULTS

Objective 1: Alternative weed management systems - Experiment #1.

Rye produced 497 g/m^2 aboveground biomass, whereas oats and wheat produced 369 and 340 g/m^2 respectively, which were statistically similar amounts (Figure 1). All cover crops delayed early-season corn growth. Detrimental effects on early-season corn growth from the oats cover crop were still apparent 7 wk after emergence, with corn height and biomass reduced 8 and 19%, respectively (Table 1). Weed biomass in non-treated plots was reduced 84, 68, and 21% by oats, rye, and wheat, respectively, 3 wk after emergence (Table 2). Oats were more inhibitory of corn and weed growth than rye, although rye produced greater surface residue, indicating possible allelopathy affects. In the presence and absence of each cover crop, atrazine plus *S*-metolachlor followed by glyphosate or sequential glyphosate applications alone were effective in providing season-long control of pitted morningglory, entireleaf morningglory, Palmer amaranth, Florida pusley, large crabgrass, and common bermudagrass (Table 3). Corn yields and gross profit margins in sequential glyphosate treated plots were equivalent or superior to the standard atrazine-based program which indicated effective and economical alternatives to atrazine are available.

Objective 1: Alternative weed management systems - Experiment #2.

A single application of glyphosate at 0.84 kg ae/ha applied at the V6 to V7 corn growth stage and a preemergence application of atrazine at 1.68 kg ai/ha plus *S*-metolachlor at 1.68 kg ai/ha supplied > 90% control of all species and similar weed biomass and yields both years (Tables 4 & 5). The cover crops rye and wheat generally aided weed suppression prior to glyphosate, but no differences in late-season control or yield occurred among cover crop treatments either year. Tillage system had little influence on weed control or weed biomass, but conservation tillage improved yields 310 to 400 kg/ha over surface tillage. Reducing the row width of corn from 76 to 38 cm improved sicklepod and arrowleaf sida control in addition to increasing yields 10 to 15%. This research shows glyphosate, cover crops, conservation tillage and narrow rows aid weed management in corn, in addition to improving yields over traditional practices involving surface tillage, wide rows, and atrazine plus *S*-metolachlor.

Objective 2: Critical period for weed control.

Diversity and density of the weed spectrum were greater both years at Blackville than at Pendleton. Weed interference duration and weed-free period curves were similar between row widths for each of the three site years. Averaged over row width, the CPWC was longer at Blackville, beginning 5 to 9 d after corn emergence (DAE) (1 to 2-lf stage) and ending 45 to 53 DAE (8 to 10-lf stage) (Figure 2). At Pendleton, the CPWC was only 4 d, beginning 21 (5-lf stage) and ending 25 DAE (5- to 6-lf stage). Light interception by corn at Blackville at the end of the CPWC was stable across years, ranging from 77 to 78%, but light interception was only 31% at Pendleton at the end of the CPWC, implying the weed density or weed spectrum may be more of a determinate of the CPWC than canopy formation. Light interception was similar between row widths throughout the growing season, which resulted in similar late-season weed biomass between row widths (Figure 3). The CPWC and crop competitiveness with late-emerging weeds appears to be similar between wide- and narrow-row corn when canopy formation does not differ between row widths. Additionally, the lack of differences in row widths in this study compared to the one near Florence may be attributed to a higher seeding rate. Therefore, other strategies such as use of a hybrid better suited for narrow rows and a lower population is likely needed to provide narrow row widths a competitive advantage over wider rows.

Figure 1. Biomass production of three small grain cover crops in late March when drill-seeded the previous fall.

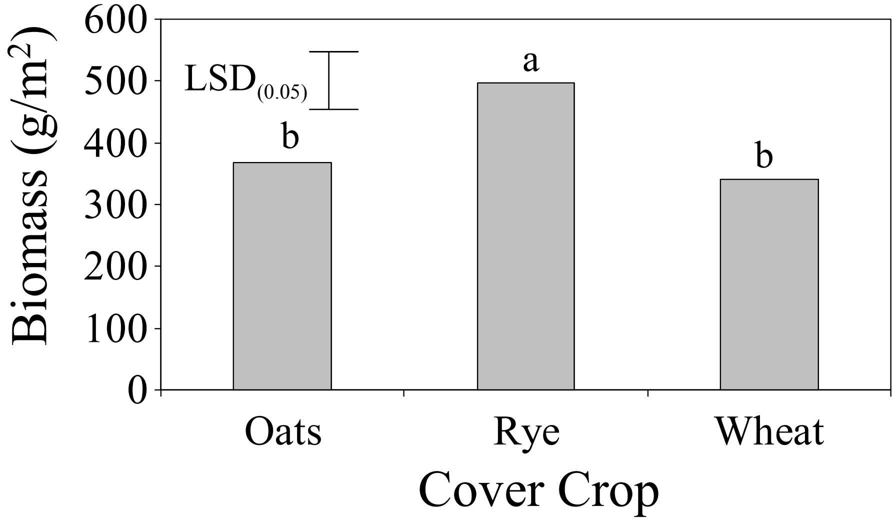

Figure 2. The influence of various weed durations (●) and weed-free (■) periods on the critical period of weed control (CPWC) in corn and relative yield of corn at Blackville, SC in 2002 and 2003, and Pendleton, SC in 2003, averaged over 48- and 97-cm row widths.

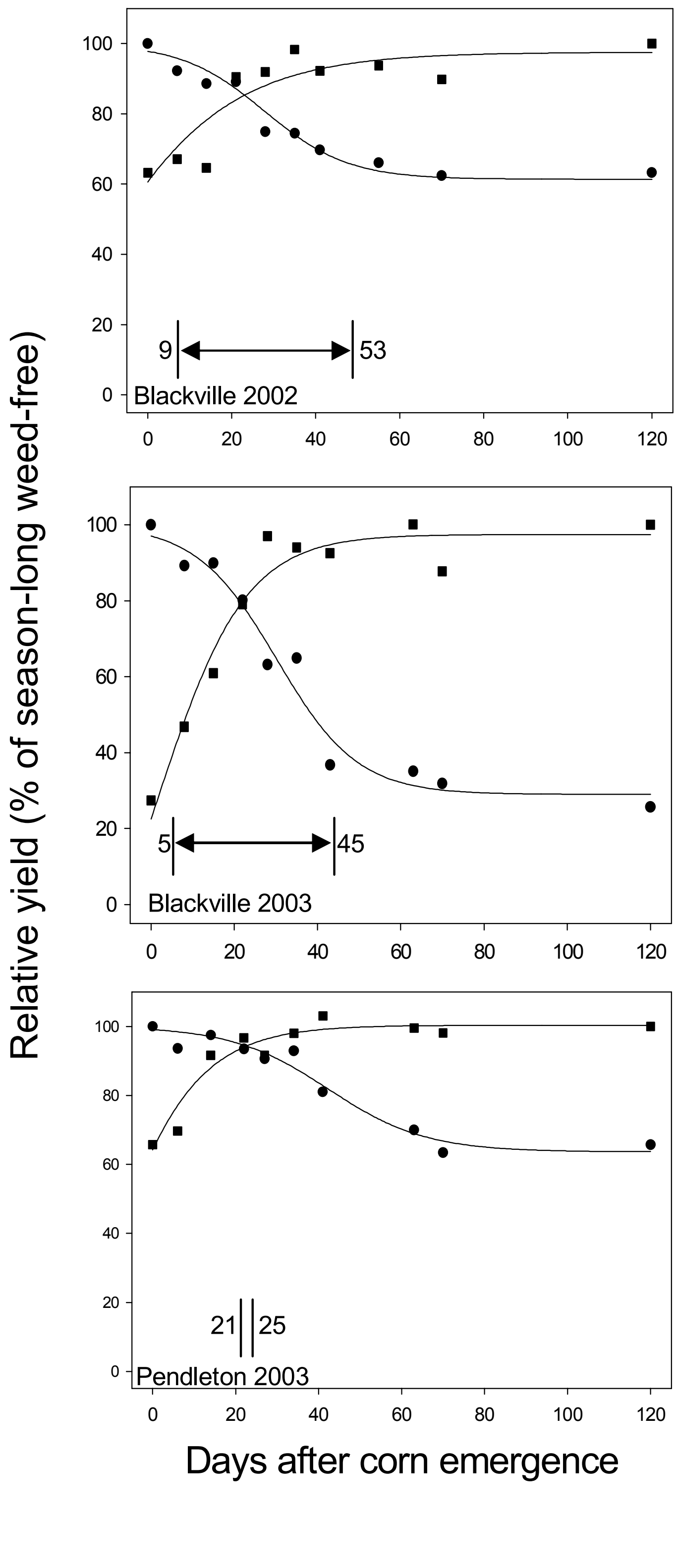

Figure 3. End-of-season weed biomass as a function of length of the critical weed-free period in corn at Blackville, SC in 2002 and 2003, and Pendleton, SC in 2003, averaged over 48- and 97-cm row widths. Equation 3 was the nonlinear regression model used to predict end-of-season weed biomass. The fitted equation was $Y = 235.25/(1 + \exp(0.2884 \times (T - 22.595)))$ for Blackville in 2002; $Y = 206.04/(1 + \exp(0.2236 \times (T - 11.992)))$ for Blackville in 2003; and $Y = 263.49/(1 + \exp(0.4453 \times (T - 8.592)))$ for Pendleton in 2003 where T is the number of days following corn emergence.

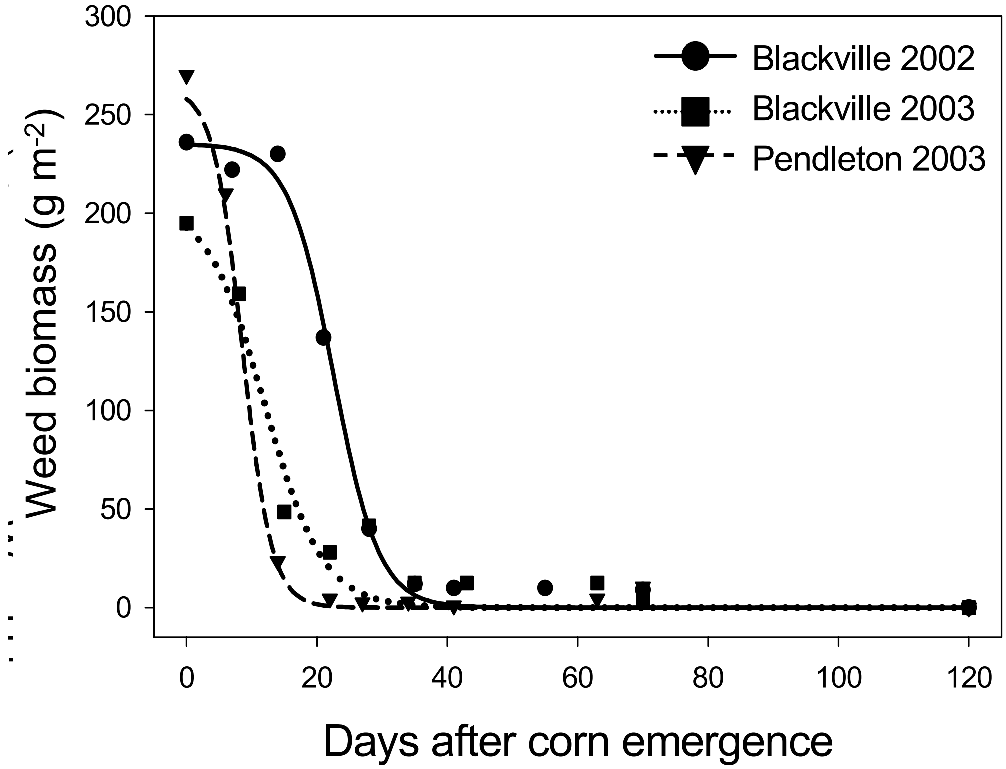

Table 1. The effect of cover crop on corn height and aboveground biomass at 3 and 7 wk after corn emergence (WAE) at Blackville, SC, averaged over 2001 and 2002.[a]

	3 WAE	7 WAE	3 WAE	7 WAE
Cover crop	height		aboveground biomass	
	cm		g/m^2	
none	48 a	169 ab	25 a	529 a
oats	42 b	156 b	17 b	429 b
wheat	44 b	175 a	18 b	457 ab
rye	43 b	171 a	18 b	517 a

[a] Means within a column followed by the same letter are not significantly different at $\alpha \leq 0.05$ according to Fisher's protected LSD test.

Table 2. Total aboveground weed biomass in nontreated cover crop plots at 3 and 5 wk after corn emergence in 2001 and 2002 at Blackville, SC.[a]

	Weed biomass			
Cover crop	3 WAE		5 WAE	
	g/m^2			
None	7.2	a	71.0	a
Oats	1.1	b	32.2	b
Rye	2.3	b	44.8	ab
Wheat	5.7	ab	19.7	b

[a] Means within a column followed by the same letter are not significantly different at $\alpha \leq 0.05$ according to Fisher's Protected LSD test. Biomass data were log transformed prior to analysis with nontransformed data shown.

[b] Non-cover crop plots (bareground) were conventionally tilled and planted, whereas corn was strip-till planted into oats, rye, and wheat plots.

Table 3. Early- and late-season pitted (IPOLA) and entireleaf morningglory (IPOHG) control in glyphosate-resistant corn at Blackville, SC.[a,b]

Cover Crop	Herbicide program	Rate	Timing	IPOLA 3 WAE	IPOLA 12 WAE	IPOHG 3 WAE	IPOHG 12 WAE
		kg ai/ha		%			
None	Nontreated			—	—	—	—
None	Atrazine + *S*-metolachlor *fb* atrazine + 1% COC	1.68 + 1.08 *fb* 1.12	PRE *fb* V3	99 a	99 a	99 a	99 a
None	Atrazine + *S*-metolachlor *fb* glyphosate	1.68 + 1.08 *fb* 1.12	PRE *fb* V7-V8[c]	98 a	98 ab	98 a	99 a
None	Glyphosate *fb* glyphosate	1.12 *fb* 1.12	V5 *fb* V7-V8	—	94 bc	—	95 ab
Wheat	Nontreated			48 c	53 d	48 c	41 cd
Wheat	Atrazine + *S*-metolachlor *fb* glyphosate	1.68 + 1.08 *fb* 1.12	PRE *fb* V7-V8	99 a	95 abc	98 a	98 a
Wheat	Glyphosate *fb* glyphosate	1.12 *fb* 1.12	V5 *fb* V7-V8	—	85 c	—	83 b
Rye	Nontreated			66 b	49 de	67 b	46 c
Rye	Atrazine + *S*-metolachlor *fb* glyphosate	1.68 + 1.08 *fb* 1.12	PRE *fb* V7-V8	99 a	97 ab	99 a	99 a
Rye	Glyphosate *fb* glyphosate	1.12 *fb* 1.12	V5 *fb* V7-V8	—	91 bc	—	94 ab
Oats	Nontreated			66 b	43 e	64 b	34 d
Oats	Atrazine + *S*-metolachlor *fb* glyphosate	1.68 + 1.08 *fb* 1.12	PRE *fb* V7-V8	99 a	97 ab	97 a	99 a
Oats	Glyphosate *fb* glyphosate	1.12 *fb* 1.12	V5 *fb* V7-V8	—	97 ab	—	98 a

[a] Means within a column followed by the same lower case letter are not significantly different at $\alpha < 0.05$ according to Fisher's Protected LSD test. Percentage control data were arcsine square root transformed prior to analysis with nontransformed data shown.

[b] Abbreviations: *fb*, followed by; PRE, preemergence; WAE, wk after corn emergence.

[c] Corn growth stages at application.

Table 4. Influence of herbicide program, cover crop, surface tillage, and row width on late-season control of sicklepod (CASOB), Palmer amaranth (AMAPA), arrowleaf sida (SIDRH), pitted morningglory (IPOLA), and broadleaf signalgrass (BRAPP) near Florence, SC in 2002 and 2003.[a]

Treatment	CASOB 2002	AMAPA 2003	SIDRH 2003	IPOLA	BRAPP
Herbicide program					
Glyphosate	97 a	99 b	95 a	93 a	95 a
Atrazine + *S*-metolachlor	90 a	100 a	96 a	92 a	99 a
Cover crop[b]					
None	97 a	99 b	96 a	94 a	97 a
Rye	97 a	100 a	92 a	89 a	95 a
Wheat	98 a	100 a	97 a	95 a	93 a
Surface tillage[c]					
None	98 a	99 a	97 a	94 a	98 a
Tilled	89 b	99 a	96 a	92 a	98 a
Row width					
Wide	92 a	99 b	93 b	91 a	97 a
Narrow	97 a	100 a	98 a	94 a	96 a

[a] Means within each treatment and year followed by the same letter are not different at $\alpha < 0.05$ based on contrasts.

[b] Atrazine plus *S*-metolachlor treatments were excluded from the comparison among cover crops because rye and wheat was not evaluated in combination with these herbicides.

[c] Rye and wheat were excluded from the comparison of surface tillage verus no surface tillage because both cover crops were only present in no surface tillage treatments.

Table 5. Influence of herbicide program, cover crop, surface tillage, and row width on late-season weed biomass and corn grain yield near Florence, SC in 2002 and 2003.[a]

	Weed biomass		Corn grain yield	
Treatment	2002	2003	2002	2003
	g/m^2		kg/ha	
Herbicide program				
Glyphosate	9 b	12 b	7130 a	5720 a
Atrazine + *S*-metolachlor	13 b	17 b	6810 a	6140 a
Nontreated	28 a	171 a	6820 a	5120 b
Cover crop[b]				
None	24 a	107 a	6790 a	5580 a
Rye	17 a	57 b	7260 a	5160 a
Wheat	16 a	94 a	7070 a	5370 a
Surface tillage[c]				
None	19 a	78 a	7040 a	5920 a
Tilled	20 a	69 a	6540 b	5610 b
Row width				
Wide	20 a	65 a	6370 b	5270 b
Narrow	17 a	88 a	7510 a	5870 a

[a] Means within each treatment and year followed by the same letter are not different at $\alpha < 0.05$ based on contrasts.

[b] Atrazine plus *S*-metolachlor treatments were excluded from the comparison among cover crops because rye and wheat was not evaluated in combination with these herbicides.

[c] Rye and wheat were excluded from the comparison of surface tillage verus no surface tillage because both cover crops were only present in no surface tillage treatments.