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Small-Grain Cover Crop Interaction with Glyphosate-Resistant Corn (*Zea mays*)[1]

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Abstract: A 2-yr field study was conducted in 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 irrigated Southeastern corn production. Oats, rye, and wheat were no-till, drill seeded each fall and subsequently desiccated in early spring before corn planting. A bareground conventional tilled treatment also was included. Within each cover crop system, the herbicides evaluated included (1) no herbicide; (2) 1.68 kg ai/ha atrazine plus 1.08 kg ai/ha *S*-metolachlor at corn planting followed by 0.84 kg ae/ha glyphosate; or (3) two applications of 0.84 kg/ha glyphosate alone, applied sequentially. All systems were compared with conventional tillage without a cover crop with 1.68 kg/ha atrazine plus 1.08 kg/ha *S*-metolachlor at planting followed by 1.12 kg/ha atrazine. Biomass of rye, oats, and wheat at dessication was 497, 369, and 340 g/m^2, respectively. 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 (WAE), with corn height and biomass reduced 8 and 19%, respectively. Weed biomass in nontreated plots was reduced 84, 68, and 21% by oats, rye, and wheat, respectively, 3 WAE. 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. Corn yields and gross profit margins in sequential glyphosate–treated plots were equivalent or superior to the standard atrazine-based program, which indicates that effective and economical alternatives to atrazine are available.

Nomenclature: Atrazine; glyphosate; *S*-metolachlor; common bermudagrass, *Cynodon dactylon* (L.) Pers. #[3] CYNDA; entireleaf morningglory, *Ipomoea hederacea* var. *integriuscula* Gray # IPOHG; Florida pusley, *Richardia scabra* L. # RCHSC; large crabgrass, *Digitaria sanguinalis* (L.) Scop. # DIGSA; Palmer amaranth, *Amaranthus palmeri* S. Wats. # AMAPA; pitted morningglory, *Ipomoea lacunosa* L. # IPOLA; corn, *Zea mays* L. 'DK662 RR'; oats, *Avena sativa* L. 'Coker 820'; rye, *Secale cereale* L. 'Wrenz'; wheat, *Triticum aestivum* L. 'Pioneer 2684'.

Additional index words: Allelopathy, conservation tillage, integrated weed management, strip tillage, transgenic corn.

Abbreviations: POST, postemergence; WAE, weeks after emergence.

INTRODUCTION

The extensive and continued use of atrazine in corn production for more than 35 yr has led to its frequent detection in surface and groundwater resources (Anonymous 1995). Atrazine detection in drinking water is a potential risk on coarse-textured soils with low organic carbon and a shallow water table (Workman et al. 1995), which is characteristic of soils in the Southeastern Coastal Plain. Although atrazine can be applied to sand and loamy sand soils, these applications must be minimized because of the risk of groundwater contamination (Anonymous 2000). However, atrazine continues to be used on more than 70% of Southeastern corn (Fernandez-Cornejo and Jans 1999). Potential environmental risk from atrazine may be mitigated by the use of alternative integrated weed management strategies.

In 1994, the Environmental Protection Agency began a special review of atrazine and other triazines because

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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.

of concerns about residues in food and drinking water (Anonymous 1995). The atrazine label prohibits mixing, loading, and application in areas having soils with a high potential for runoff or leaching; limits the quantity of atrazine that can be applied during a growing season; and restricts applications adjacent to surface and groundwater resources (Anonymous 2000). In recent surveys, atrazine was detected in 72% of the samples collected in surface waters across Mid-Atlantic States (Ferrari et al. 1997), with similar results in North Carolina, where 83% of the sampled wells contained atrazine (Wade et al. 1998).

The broad-spectrum herbicide glyphosate is now labeled for postemergence (POST) application in glyphosate-resistant corn through the V8 growth stage or 76-cm height (Anonymous 2002b). Glyphosate has several advantageous characteristics including a lack of soil activity, tight binding to soil colloids, low mammalian toxicity (Vencill 2002), and nonpersistence in the environment (Haney et al. 2000). Development of integrated weed management systems centered on glyphosate and other sustainable practices could be more profitable and sustainable than depending on traditional systems centered around atrazine and conventional preplant tillage.

Small-grain cover crops and conservation tillage management may aid early-season weed suppression in corn. Cover crops have been extensively evaluated for weed suppression, but most research has been conducted on high-value horticultural crops where herbicide availability is often limited. Evaluation of cover crops for weed control in corn and integration of cover crops with other management tactics, such as conservation tillage and a herbicide-resistant hybrid, may reduce reliance on atrazine. Furthermore, cover crops could provide economical weed management regimes for land areas in which atrazine is currently prohibited or water quality is a concern. A high level of early-season weed suppression can be obtained with rye and wheat cover crops (Smeda and Weller 1996; Yenish et al. 1996; Zasada et al. 1997). Rye and wheat residues alone can reduce *Amaranthus* spp. canopy volume as much as 71% (Williams et al. 1998). In addition to weed suppression, cover crops build up surface residues in conservation tillage systems (Bauer and Reeves 1999), reduce surface runoff (Cassel et al. 1995), and lessen the rate of soil moisture depletion (Teasdale and Mohler 1993).

The objectives of this research were to test and economically assess weed control strategies for irrigated corn that incorporate glyphosate and conservation production practices known to limit herbicide off-site movement compared with a traditional system relying heavily on atrazine.

MATERIALS AND METHODS

A field study was conducted at the Edisto Research and Education Center near Blackville, SC, from November 2001 through corn harvest in 2002 and from November 2002 through corn harvest in 2003 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. The soil type both years was a Dunbar sandy loam (fine, kaolinitic, thermic Aeric Paleaquults) with 0.6% organic matter and pH of 6.0 in 2001 and 5.9 in 2002. 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 seeded in 19-cm rows on November 15 each year at 78, 112, and 112 kg/ha, respectively, and subsequently killed with 0.84 kg ae/ha glyphosate on March 28, 2001, and March 15, 2002, 2 wk before corn planting. Nitrogen at 34 kg/ha was applied to the cover crops in late February to ensure adequate growth before dessication. Cover crop aboveground biomass was harvested from four random 0.5-m^2 quadrats in each cover crop on the day of dessication, oven dried at 60 C for 2 wk, and then weighed. A bareground, conventional tilled system was included for comparison. After glyphosate dessication of winter weeds, bareground plots were disked twice and then bedded and subsoiled with an in-row shank to a 36-cm depth in a single pass. '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 31-cm tillage strip in which corn was seeded. All plots were seeded at 69,000 seeds/ha in 97-cm-wide rows the first week of April, and approximately 2.5 to 5 cm of overhead irrigation was applied weekly throughout the growing season in the absence of rainfall. Corn was sidedressed with 112 kg/ha nitrogen at the V8 stage. 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-tall corn followed by

0.84 kg/ha glyphosate at 76-cm-tall corn. A standard atrazine-based system was evaluated only in bareground, conventional tilled plots. The standard system comprised 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-tall corn. Plots consisted of four 9-m rows, and cover crop and herbicide programs were replicated four times. Tillage and corn planting was performed parallel to the cover crop strips. Cover crop plots were 4.5 m wide, whereas the four planted corn rows were 3.8 m wide; thus, a border existed among cover crops and between strip-tilled and conventionally tilled plots. The burndown glyphosate application was applied to the entire test area with a tractor-mounted sprayer equipped with flat-fan nozzles calibrated for glyphosate at 122 L/ha. All in-crop herbicides were applied with a CO_2-pressurized backpack equipped with flat-fan nozzles calibrated at 187 L/ha for atrazine and *S*-metolachlor and 94 L/ha for glyphosate.

Pitted morningglory, entireleaf morningglory, Palmer amaranth, Florida pusley, large crabgrass, and common bermudagrass infested the plot area in 2001, whereas pitted morningglory, entireleaf morningglory, Florida pusley, and Palmer amaranth were present in 2002. 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 three 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. Variable costs for the 13 experimental treatments are listed in Table 1. 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 those of in-crop applications for corn. However, conventional tillage system plots normally do not receive glyphosate before disking; thus, use of glyphosate for cover crop dessication would be an added expense compared with a conventional tillage system. Gross return was the product of grain yield and a 2002 enterprise budget price of 9.67 cents per kilogram of grain. Gross profit margin was calculated by subtracting variable cost from gross return.

To allow comparison with the standard atrazine-based program, the experiments were conducted in a randomized complete block design, and data were subjected to ANOVA. When comparisons were made among cover crops, a 3- by 4-factorial analysis of data was conducted. To homogenize variances, weed control data were analyzed using arcsine square-root–transformed data, and weed biomass analyses were conducted on log-transformed data. Year interactions were tested and data combined over years when appropriate. Means were separated using Fisher's protected LSD test at $\alpha \leq 0.05$.

RESULTS AND DISCUSSION

Cover Crop Biomass. Aboveground cover crop biomass differed between years and cover crops, but the interaction of cover crop and year was nonsignificant. Biomass production in 2001 was one-third greater than in 2002, likely because of earlier dessication in 2002 than in 2001 along with spring temperature differences between years. Averaged over both years, 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). These biomass quantities are similar to those reported in other small-grain cover crop research conducted on the Southeastern Coastal Plain (Bauer and Reeves 1999).

Corn Density and Growth. Corn density was similar between years and did not differ among cover crop treatments 3 and 7 WAE (data not shown). The interaction of cover crop and year was nonsignificant 3 and 7 WAE for corn height and biomass; thus, data were combined over years. Corn height and biomass 3 WAE were less in each cover crop compared with noncover plots; however, among cover crops, corn height did not differ (Table 2). Although soil temperature among cover crop treatments was not monitored, early-season delay in corn growth is generally attributed to cooler soil temperatures beneath residues (Fortin and Pierce 1991; Teasdale and Mohler 1993). Rye, which had the greatest amount of surface residue, produced corn biomass statistically equivalent to that produced in noncover plots 7 WAE, indicating that corn was able to overcome the early developmental delay caused by rye. Additionally, the rye cover crop may have benefited corn as summer temper-

Table 1. Variable costs associated with weed management systems in corn.[a]

Cover crop	Herbicide program	Corn seed	Cover crop seed	Herbicide	Other[b]	Variable costs
		($/ha)				
None	Nontreated	64.22	0	21.02	22.03	107.27
None	Atrazine + *S*-metolachlor fb atrazine + 1% COC	64.22	0	69.31	45.23	178.75
None	Atrazine + *S*-metolachlor fb glyphosate	78.99	0	81.04	45.23	205.26
None	Glyphosate fb glyphosate	78.99	0	63.06	46.98	189.03
Wheat	Nontreated	64.22	32.11	21.02	36.16	153.51
Wheat	Atrazine + *S*-metolachlor fb glyphosate	78.99	32.11	81.04	40.09	232.23
Wheat	Glyphosate fb glyphosate	78.99	32.11	63.06	67.80	241.96
Rye	Nontreated	64.22	34.65	21.02	36.16	156.05
Rye	Atrazine + *S*-metolachlor fb glyphosate	78.99	34.65	81.04	40.09	234.77
Rye	Glyphosate fb glyphosate	78.99	34.65	63.06	67.80	244.51
Oats	Nontreated	64.22	39.22	21.02	36.16	160.62
Oats	Atrazine + *S*-metolachlor fb glyphosate	78.99	39.22	81.04	40.09	239.34
Oats	Glyphosate fb glyphosate	78.99	39.22	63.06	67.80	249.07

[a] Abbreviations: COC, crop oil concentrate; fb, followed by.

[b] Other costs include field preparation, planting, application, and labor costs.

atures rose. Cover crop residues lower daily soil maximum temperature and soil temperature amplitude (Teasdale and Mohler 1993), which may be important in June and July, when air and soil temperatures rise sharply. Furthermore, surface residues from cover crops reduce the rate of soil moisture depletion compared with barren soil (Teasdale and Mohler 1993), which is extremely important on the sandy soils of the Southeastern Coastal Plain, where moisture retention on these coarse-textured soils is low. Conversely, based on corn biomass data, oats were inhibitory to corn compared with rye and nocover 7 WAE. Corn produced 529 g/m^2 aboveground biomass by 7 WAE in noncover plots, whereas only 429 g/m^2 was produced in oats (Table 2).

Weed Biomass and Control. In 2001, an 81 to 99% range in early-season weed control in plots treated with herbicides resulted in similar weed biomass among these plots (data not shown). In 2002, weed biomass was sampled by species only in nontreated plots. Because of the limited sample area and uneven distribution of species, no differences in weed biomass among non–herbicide-treated cover crop plots were detected for any single species in either year. However, when weed biomass was pooled over species, differences did exist among nontreated cover crops. Averaged over 2001 and 2002, weed biomass was reduced 84, 68, and 21% by oats, rye, and wheat, respectively, compared with nontreated, noncover plots 3 WAE (Table 3). Oats had less soil surface residue than rye but the greatest inhibition of weed biomass; therefore, allelopathy probably contributed to weed suppression by oats. All cover crops provided >35% weed biomass suppression through 5 WAE compared with noncover plots (Table 3), which may be extremely beneficial when relying solely on a nonresidual, POST herbicide.

Pitted and entireleaf morningglory control was similar among nontreated rye and oat cover crops 3 WAE, where both rye and oats provided significantly greater suppression than wheat (Table 4). None of the cover

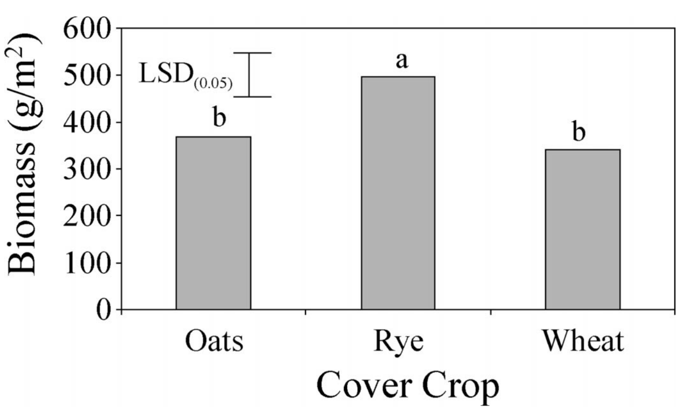

Figure 1. Biomass production of three small-grain cover crops in late March when drill seeded in mid-November at Blackville, SC, averaged over the 2000–2001 and 2001–2002 growing seasons. Oats, rye, and wheat were seeded at 78, 112, and 112 kg/ha, respectively.

Table 2. 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]

Cover crop	Height 3 WAE	Height 7 WAE	Aboveground biomass 3 WAE	Aboveground biomass 7 WAE
	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 3. Total aboveground weed biomass in nontreated cover crop plots at 3 and 5 wk after corn emergence (WAE) in 2001 and 2002 at Blackville, SC.[a,b]

Cover crop	Weed biomass	
	3 WAE	5 WAE
	g/m²	
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 before analysis with nontransformed data shown.

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

crops alone provided control equivalent to herbicide-treated plots. Sequential glyphosate applications were not rated at 3 WAE because the initial application had just been applied. Pitted and entireleaf morningglory ratings 3 WAE show suppression from the cover crop alone or cover crop in combination with atrazine plus *S*-metolachlor. At 3 WAE, atrazine plus *S*-metolachor provide 98% or greater control of both morningglory species with or without a cover crop. Although pitted morningglory control ≥85% was obtained with sequential glyphosate applications through 12 WAE, only one of four sequential glyphosate treatments provided control equivalent to the standard program of atrazine plus *S*-metolachlor followed by atrazine, likely because of the greater effectiveness of atrazine and *S*-metolachlor on pitted morningglory than glyphosate alone. In glyphosate-resistant soybean, partial control of pitted morningglory usually occurs with application of glyphosate alone or sequential applications (Norsworthy and Oliver 2002).

At 3 WAE, oats and rye suppressed Palmer amaranth 69 and 77%, respectively, which was greater than the 53% suppression observed in wheat (Table 5). Palmer amaranth control 3 and 12 WAE was equivalent among herbicide-treated plots, exceeding 95% (Table 5). Pigweed species including Palmer amaranth are common in southern U.S. corn (Webster and Coble 1997). Nontreated rye and wheat cover crops provided only 41 and 42% Florida pusley suppression, respectively, through 12 WAE, which was less than the 60% provided by oats. Sequential glyphosate applications or atrazine plus *S*-metolachlor followed by glyphosate were effective in controlling Florida pusley, providing ≥87% control, regardless of cover crop presence or absence of cover crop species. However, it is important to note that Florida pusley control with glyphosate is highly contingent upon size at application (Murdock and Sherrick 1998). Control diminishes notably when Florida pusley is more than 5 cm tall (Murdock and Sherrick 1998).

Common bermudagrass and large crabgrass were present at rateable densities only in 2001. Sequential glyphosate applications were effective in providing season-long large crabgrass control comparable to that provided by all atrazine-based programs (Table 6). Atrazine and *S*-metolachlor were ineffective in controlling common bermudagrass, which may explain why common bermudagrass has become an increasingly prominent weed in southern U.S. corn from 1973 to 1995 (Webster and Coble 1997). Likewise, the cover crops were relatively

Table 4. Early- and late-season pitted (IPOLA) and entireleaf morningglory (IPOHG) control in glyphosate-resistant corn at Blackville, SC, averaged over 2001 and 2002.[a,b]

Cover crop	Herbicide program	Rate	Timing	IPOLA		IPOHG	
				3 WAE	12 WAE	3 WAE	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 lowercase letter are not significantly different at $\alpha < 0.05$ according to Fisher's protected LSD test. Percent control data were arcsine square-root transformed before analysis with nontransformed data shown.

[b] Abbreviations: COC, crop oil concentrate; fb, followed by; PRE, preemergence; WAE, weeks after corn emergence.

[c] Corn growth stages at application.

Table 5. Early- and late-season Palmer amaranth (AMAPA) and Florida pusley (RCHSC) control in glyphosate-resistant corn at Blackville, SC, averaged over 2001 and 2002.[a,b]

Cover crop	Herbicide program	Rate	Timing	AMAPA 3 WAE	AMAPA 12 WAE	RCHSC 3 WAE	RCHSC 12 WAE
		kg ai/ha		%			
None	Nontreated			—	—	—	—
None	Atrazine + *S*-metolachlor fb atrazine + 1% COC	1.68 + 1.0 fb 1.12	PRE fb V3	99 a	99 a	99 a	96 a
None	Atrazine + *S*-metolachlor fb glyphosate	1.68 + 1.0 fb 1.12	PRE fb V7–V8[c]	99 a	100 a	99 a	95 ab
None	Glyphosate fb glyphosate	1.12 fb 1.12	V5 fb V7–V8	—	100 a	—	88 ab
Wheat	Nontreated			53 c	49 c	69 c	42 d
Wheat	Atrazine + *S*-metolachlor fb glyphosate	1.68 + 1.0 fb 1.12	PRE fb V7–V8	99 a	99 a	96 a	94 ab
Wheat	Glyphosate fb glyphosate	1.12 fb 1.12	V5 fb V7–V8	—	96 a	—	87 b
Rye	Nontreated			77 b	53 bc	82 b	41 d
Rye	Atrazine + *S*-metolachlor fb glyphosate	1.68 + 1.0 fb 1.12	PRE fb V7–V8	99 a	99 a	98 a	97 a
Rye	Glyphosate fb glyphosate	1.12 fb 1.12	V5 fb V7–V8	—	97 a	—	90 ab
Oats	Nontreated			69 b	66 b	74 bc	60 c
Oats	Atrazine + *S*-metolachlor fb glyphosate	1.68 + 1.0 fb 1.12	PRE fb V7–V8	99 a	99 a	93 a	96 ab
Oats	Glyphosate fb glyphosate	1.12 fb 1.12	V5 fb V7–V8	—	99 a	—	90 ab

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

[b] Abbreviations: COC, crop oil concentrate; fb, followed by; PRE, preemergence; WAE, weeks after corn emergence.

[c] Corn growth stages at application.

ineffective in suppressing common bermudagrass, although control was equivalent to that provided by atrazine plus *S*-metolachlor. Conversely, single and sequential glyphosate applications were effective in controlling common bermudagrass, providing >95% control through 12 WAE. A single glyphosate application at 0.84 kg/ha without a preemergence herbicide is generally ineffective in providing a high level of extended common bermudagrass control (Anonymous 2002b). The high level of control observed in this study was attributed to the rapid development of a dense canopy after the final glyphosate application. Furthermore, bermudagrass is shade intolerant (Hart et al. 1970) and was thus unable to flourish beneath the corn canopy because of the combined effects of glyphosate and the low-light environment.

Variable Costs, Corn Yield, and Gross Profit Margin. All systems that involved glyphosate and a cover crop had variable costs ranging from $232/ha to $249/ha (Table 1). The standard program of atrazine plus *S*-metolachlor followed by atrazine had the lowest variable cost of any herbicide treatment at $179/ha. Conventional rather than glyphosate-resistant seed costs and the absence of a cover crop were two factors that contributed most to this savings.

Table 6. Early- and late-season large crabgrass (DIGSA) and common bermudagrass (CYNDA) control in glyphosate-resistant corn at Blackville, SC, in 2001.[a,b]

Cover crop	Herbicide program	Rate	Timing	DIGSA 3 WAE	DIGSA 12 WAE	CYNDA 3 WAE	CYNDA 12 WAE
		kg ai/ha		%			
None	Nontreated			—	—	—	—
None	Atrazine + *S*-metolachlor fb atrazine + 1% COC	1.68 + 1.0 fb 1.12	PRE fb V3	99 a	100 a	26 a	38 b
None	Atrazine + *S*-metolachlor fb glyphosate	1.68 + 1.0 fb 1.12	PRE fb V7–V8[c]	99 a	100 a	33 a	98 a
None	Glyphosate fb glyphosate	1.12 fb 1.12	V5 fb V7–V8	—	100 a	—	100 a
Wheat	Nontreated			49 c	30 c	29 a	42 b
Wheat	Atrazine + *S*-metolachlor fb glyphosate	1.68 + 1.0 fb 1.12	PRE fb V7–V8	99 a	99 a	35 a	98 a
Wheat	Glyphosate fb glyphosate	1.12 fb 1.12	V5 fb V7–V8	—	100 a	—	100 a
Rye	Nontreated			78 b	55 b	26 a	50 b
Rye	Atrazine + *S*-metolachlor fb glyphosate	1.68 + 1.0 fb 1.12	PRE fb V7–V8	99 a	100 a	29 a	98 a
Rye	Glyphosate fb glyphosate	1.12 fb 1.12	V5 fb V7–V8	—	100 a	—	98 a
Oats	Nontreated			76 b	23 c	35 a	49 b
Oats	Atrazine + *S*-metolachlor fb glyphosate	1.68 + 1.0 fb 1.12	PRE fb V7–V8	99 a	99 a	34 a	97 a
Oats	Glyphosate fb glyphosate	1.12 fb 1.12	V5 fb V7–V8	—	100 a	—	99 a

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

[b] Abbreviations: COC, crop oil concentrate; fb, followed by; PRE, preemergence; WAE, weeks after corn emergence.

[c] Corn growth stages at application.

Table 7. Variable costs, corn grain yield, and gross profit margins from combinations of cover crops and herbicide programs in corn.[a]

Cover crop	Herbicide program	2001 Yield	2001 Gross profit margin	2002 Yield	2002 Gross profit margin
		kg/ha	$/ha	kg/ha	$/ha
None	Nontreated	8,680 de	732 cd	7,270 bcd	596 abc
None	Atrazine + *S*-metolachlor fb atrazine + 1% COC	9,730 bcd	763 bcd	10,040 a	792 a
None	Atrazine + *S*-metolachlor fb glyphosate	11,110 a	869 ab	9,990 ab	761 ab
None	Glyphosate fb glyphosate	11,160 a	890 a	9,810 abc	760 ab
Wheat	Nontreated	8,980 cd	715 d	6,920 d	515 bc
Wheat	Atrazine + *S*-metolachlor fb glyphosate	10,490 ab	782 abcd	8,440 abcd	583 abc
Wheat	Glyphosate fb glyphosate	10,850 ab	807 abcd	8,920 abcd	621 abc
Rye	Nontreated	8,970 cd	711 d	7,190 cd	539 abc
Rye	Atrazine + *S*-metolachlor fb glyphosate	11,060 a	834 abc	8,370 abcd	575 abc
Rye	Glyphosate fb glyphosate	11,270 a	846 abc	8,860 abcd	612 abc
Oats	Nontreated	7,500 e	565 e	6,460 d	464 c
Oats	Atrazine + *S*-metolachlor fb glyphosate	10,180 abc	745 cd	8,710 abcd	603 abc
Oats	Glyphosate fb glyphosate	10,130 abc	731 cd	8,630 abcd	585 abc

[a] Abbreviations: COC, crop oil concentrate; fb, followed by.

The interaction of year with grain yield and gross profit margin was significant; therefore, results are presented separately for each year. The presence of common bermudagrass in 2001 contributed to the observed yield and gross profit margin differences between years. Grain yields in rye and noncover plots receiving atrazine plus *S*-metolachlor followed by glyphosate or sequential glyphosate applications were superior to those in the standard program in 2001 (Table 7). Conversely, grain yields in oats and wheat receiving atrazine plus *S*-metolachlor followed by glyphosate or sequential glyphosate applications alone were equivalent to those in the standard program. The lack of common bermudagrass control with atrazine plus *S*-metolachlor likely suppressed yields in the standard program in 2001. In 2002, yields were not statistically different for all herbicide-treated plots. Among cover crops, yields were statistically similar, but yields were numerically lowest in the oats cover crop. In nontreated plots in both years, grain yields were reduced compared with the standard program regardless of cover crop, indicating that at the weed densities present, each cover crop could not provide adequate weed suppression for optimum yields.

Sequential glyphosate applications in the absence of a cover crop provided a gross profit margin $128/ha greater than that of the standard program in 2001 (Table 7). Gross profit margins from all other herbicide-treated plots were comparable to that of the standard program. Only nontreated oats had a gross profit margin lower than that of the standard program.

All herbicide-treated plots produced gross profit margins similar to that of the standard program in 2002; however, as in 2001, the numerically lowest yield and gross profit margin was in nontreated oats, which had a yield and gross profit margin of 6,460 kg/ha and $464/ha, respectively. Weed suppression in nontreated oat plots in 2001 was greater than that in all other nontreated plots 7 WAE (data not shown); thus, yield differences among noncover plots cannot be explained by a lack of weed control. However, corn development and growth delays caused by oats likely contributed to lower corn yields. In large-plot demonstrations 2 yr before this research, a similar reduction in corn biomass and ultimately in yield was noted when corn followed oats grown as winter forage for livestock (W. M. Hair, personal communication). Additionally, researchers in Michigan suggest that oat straw may be allelopathic to corn because soil thermal conditions were unable to fully account for developmental differences between mulched and bare soil plots (Fortin and Pierce 1991).

All three of the small grains were effective in reducing early-season weed biomass; however, the use of oats as a cover crop would not be advisable because of its deleterious effect on corn development, growth, and yield. Because the quantity of physical mulch on the soil surface directly affects weed emergence (Teasdale et al. 1991; Vidal and Bauman 1996), efforts should be made to maximize cover crop growth before dessication. A nitrogen application was used in this research in an attempt to maximize cover crop biomass production. Another less-costly way to produce sizeable biomass would be to seed earlier in the fall. Seeding small-grain cover crops in October results in greater biomass production by early April compared with seeding in November or December on the Southeastern Coastal Plain (Bauer and Reeves 1999).

When using a soil-applied atrazine program, there was no benefit from a cover crop for further improvements in early-season weed control (Tables 4–6). Conversely, using a cover crop in a total POST weed management system would provide early-season weed suppression before herbicide application. Atrazine plus *S*-metolachlor followed by glyphosate or sequential glyphosate applications alone provide a high level of weed control; thus, atrazine use can be reduced or eliminated. Furthermore, common bermudagrass, which is an increasingly prominent weed, will be controlled more effectively with glyphosate than with atrazine and *S*-metolachlor.

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LITERATURE CITED

Anonymous. 1995. Special Review Report: The Facts About Atrazine and Simazine. Greensboro, NC: Ciba Crop Protection. 37 p.

Anonymous. 2000. Crop Protection Reference. New York: C & P. Pp. 1530–1535.

Anonymous. 2002a. Agronomic Crop Enterprise Budgets, South Carolina, 2002 Season: Web page: http://www.cherokee.agecon.clemson.edu/crop_bud.htm. Accessed: September 2002.

Anonymous. 2002b. Roundup WeatherMax Herbicide: Web page: http://www.cdms.net/ldat/ld5UJ000.pdf. Accessed: September 2002.

Bauer, P. J. and D. W. Reeves. 1999. A comparison of winter cereal species and planting dates as residue cover for cotton grown with conservation tillage. Crop Sci. 39:1824–1830.

Cassel, D. K., C. W. Raczkowski, and H. P. Denton. 1995. Tillage effects on corn production and soil physical conditions. Soil Sci. Soc. Am. J. 59: 1436–1443.

Fernandez-Cornejo, J. and S. Jans. 1999. Pest Management in U.S. Agriculture. Economic Research Service, USDA. Agricultural Handbook No. 717. Web page: http://www.ers.usda/gov/publications/. Accessed: August 1999.

Ferrari, M. J., S. W. Ator, J. D. Blomquist, and J. E. Dysart. 1997. Pesticides in Surface Waters of the Mid-Atlantic Region. USGS Water-Resources Investigative Rep. 97-4280. Washington, DC: U.S. Department of Agriculture. Pp. 1–16.

Fortin, M. C. and F. J. Pierce. 1991. Timing and nature of mulch retardation of corn vegetative development. Agron. J. 83:258–263.

Haney, R. L., S. A. Senseman, F. M. Hons, D. A. Zuberer. 2000. Effect of glyphosate on soil microbial activity and biomass. Weed Sci. 48:89–93.

Hart, R. H., R. E. Hughes, C. E. Lewis, and W. G. Monson. 1970. Effect of nitrogen and shading on yield and quality of grasses grown under young slash pines. Agron. J. 62:285–287.

Murdock, E. C. and S. Sherrick. 1998. Florida pusley (*Richardia scabra*) control in Roundup Ready soybeans. Proc. South. Weed Sci. Soc. 52: 57–58.

Norsworthy, J. K. and L. R. Oliver. 2002. Effect of irrigation, soybean density, and glyphosate on hemp sesbania (*Sesbania exaltata*) and pitted morningglory (*Ipomoea lacunosa*) interference in drill-seeded soybean. Weed Technol. 16:7–17.

Smeda, R. J. and S. C. Weller. 1996. Potential of rye (*Secale cereale*) for weed management in transplanted tomatoes (*Lycopersicon esculentum*). Weed Sci. 44:596–602.

Teasdale, J. R., C. E. Beste, and W. E. Potts. 1991. Response of weeds to tillage and cover crop residue. Weed Sci. 39:195–199.

Teasdale, J. R. and C. L. Mohler. 1993. Light transmittance, soil temperature, and soil moisture under residue of hairy vetch and rye. Agron. J. 85: 673–680.

Vencill, W. K., ed. 2002. Herbicide Handbook. 8th ed. Lawrence, KS: Weed Science Society of America. 493 p.

Vidal, R. A. and T. T. Bauman. 1996. Surface wheat (*Triticum aestivum*) residues, giant foxtail (*Setaria faberi*), and soybean (*Glycine max*) yield. Weed Sci. 44:939–943.

Wade, H. F., A. C. York, A. E. Morey, J. M. Padmore, and K. M. Rudo. 1998. The impact of pesticide use on groundwater in North Carolina. J. Environ. Qual. 27:1018–1026.

Webster, T. M. and H. D. Coble. 1997. Changes in the weed species composition of the southern United States: 1974 to 1995. Weed Technol. 11: 308–317.

Williams, M. M., III, D. A. Mortensen, and J. W. Doran. 1998. Assessment of weed and crop fitness in cover crop residues for integrated weed management. Weed Sci. 46:595–603.

Workman, S. R., A. D. Ward, N. R. Fausey, and S. E. Nokes. 1995. Atrazine and alachlor dissipation rates from field experiments. Trans. ASAE 38: 1421–1425.

Yenish, J. P., A. D. Worsham, and A. C. York. 1996. Cover crops for herbicide replacement in no-tillage corn (*Zea mays*). Weed Technol. 10:815–821.

Zasada, I. A., H. M. Linker, and H. D. Coble. 1997. Initial weed densities affect no-tillage weed management with a rye (*Secale cereale*) cover crop. Weed Technol. 11:473–477.