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Integrated weed management strategies for maize (*Zea mays*) production on the southeastern coastal plains of North America

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Abstract

A 2-yr field study was conducted near Florence, South Carolina, to compare alternative versus traditional *Zea mays* (L.) production practices for effectiveness of weed control on the southeastern Coastal Plain. Alternative practices included conservation tillage, 38-cm row widths, cover crops, and glyphosate, whereas traditional production practices involved surface tillage, 76-cm row widths, and atrazine plus metolachlor. *Ipomoea lacunosa* (L.) and *Brachiaria platyphylla* (Griseb.) Nash were present in the study both years, whereas *Senna obtusifolia* (L.) Irwin and Barneby was present only in 2002 and *Amaranthus palmeri* (S.) Wats. and *Sida rhombifolia* (L.) in 2003. Glyphosate applied at the V6–V7 *Z. mays* growth stage and a pre-emergence application of atrazine plus *S*-metolachlor both resulted in greater than 90% control of all weed species and similar weed biomass and yields both years. A *Secale cereale* (L.) or *Triticum aestivum* (L.) cover crop usually suppressed most weed species prior to glyphosate application, but had no effect on late-season weed control or grain yield in either year. Surface tillage had little effect on weed control or weed biomass, but omitting surface tillage increased yields an average of 310–400 kg/ha. Reducing the row width of *Z. mays* improved *S. obtusifolia* and *Sida rhombifolia* control while increasing grain yields 10–15%. In addition to increasing grain yields, the use of glyphosate, cover crops, conservation tillage, and narrow rows are important weed management practices that can be integrated into *Z. mays* production systems on the southeastern Coastal Plain of the United States.
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1. Introduction

Atrazine and metolachlor are two of the most commonly used herbicides for *Zea mays* production in the United States (Fernandez-Cornejo and Jans, 1999). The extensive and continued use of atrazine and metolachlor mainly in *Z. mays* production has led to these herbicides being detected in surface and groundwater resources throughout the southeastern Coastal Plains (Holman et al., 2000; Novak et al., 2001). Because of the potential negative impact of atrazine and metolachlor on water quality, alternative methods of weed control are needed that will result in similar or higher crop productivity and provide the same or greater level of weed control. Integrated weed management strategies that involve narrow row widths, conservation tillage, and cover crops may be utilized to increase the competitiveness of *Z. mays* with weeds and to minimize off-site herbicide movement. Integration of these factors with herbicides with reduced environmental impact may further reduce atrazine and metolachlor use and result in more effective weed management practices for areas where atrazine is currently prohibited or water quailty is a concern.

There has been renewed interest in using narrow-row spacings (<76 cm) for *Z. mays* production throughout the United States. Much of this interest is due to the fact that narrow-row spacing can increase the

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competitiveness of the crop with weeds, reducing the amount or frequency of herbicides applied (Forcella et al., 1992; Teasdale, 1995). *Z. mays* grain yield increases with narrow row widths have been reported in several studies (Bullock et al., 1988; Fulton, 1970; Murphy et al., 1996; Porter et al., 1997), but not in others (Johnson et al., 1998; Jones et al., 2001; Norsworthy and Oliveira, 2004; Ottman and Welch, 1989; Tharp and Kells, 2001b; Westgate et al., 1997), indicating climatic, management, and/or soil factors may affect crop responses to narrow row widths. On the southeastern Coastal Plain, Busscher et al. (2002) and Bauer et al. (2002) reported that increases in *Z. mays* grain yield due to reductions in row width were greater when both deep and no surface tillage were used and that soil moisture status has a significant impact on *Z. mays* yield responses to row width. Soil moisture effects on crop row width responses have also previously been reported for *Z. mays* (Fulton, 1970) and *Glycine max* (Frederick et al., 1998). Reductions in *Z. mays* grain yield (DeSousa et al., 2003) or weed suppression (Johnson and Hoverstad, 2002) with narrow row widths have seldom been found and were usually inconsistent over years.

Investigations into the use of *Secale cereale* as a cover crop for *Z. mays* has also lead to varying results. Mohler (1991) reported that a *S. cereale* mulch effectively reduced weed biomass in sweet corn without detrimentally affecting grain yield. Conversely, others found *Z. mays* yields to be diminished when seeded behind *S. cereale* compared with no cover crop (Burgos and Talbert, 1996; Rainbault et al., 1990; Tollenaar et al., 1993). These differences in *Z. mays* responses to planting a *S. cereale* cover crop may be attributed to differences in residue amounts among research sites or differences in allelochemical production among *S. cereale* cultivars (Burgos et al., 1999; Tollenaar et al., 1993). Both *S. cereale* and *Triticum aestivum* cover crops are effective in suppressing early season weed growth, but may delay *Z. mays* development without reducing grain yield (Norsworthy, 2004). Cover crops can reduce herbicide needs with conservation-tillage *Z. mays* systems (Gallagher et al., 2003). Early season weed suppression provided by a *S. cereale* or *T. aestivum* cover crop can replace the need for a pre-emergence application of atrazine plus metolachlor (Gallagher et al., 2003; Norsworthy, 2004). In addition to providing a physical barrier to weed emergence, plant residues reduce the quantity of light reaching the soil surface and alter light quality, which in turn lessens emergence of many weeds (Teasdale and Mohler, 2000).

There has been a substantial increase in recent years in the use of conservation tillage practices in the United States (Sandretto, 2001). Conservation tillage reduces soil erosion and increases water infiltration (Bentley, 1985) and consequently, results in less off-site movement of pesticides. Although adoption of conservation tillage is gaining widespread acceptance throughout the United States, conventional tillage practices in the southeastern United States still predominate (Norsworthy, 2003). These conventional tillage practices commonly involve disking, field cultivating, and deep tillage to disrupt the E horizon (natural hardpan). Deep tillage implements are also available that disrupt the E horizon with minimum surface disturbance, in turn increasing grain yields on the southeastern Coastal Plain (Bauer et al., 2002; Busscher et al., 2002; Frederick and Bauer, 1996; Frederick et al., 1998; Khalilian et al., 1988), especially during periods of limited rainfall. In addition to reducing soil erosion and improving soil quality, leaving plant residues on the soil surface reduces weed emergence (Teasdale et al., 1991; Teasdale and Mohler, 2000; Vidal and Bauman, 1996). Eliminating surface tillage generally diminishes emergence of large-seeded, annual weeds (Buhler, 1995). Thus, conservation tillage systems that minimize disturbance of surface residues should reduce emergence of at least some weed species and ultimately weed biomass and interference with crops.

Although use of cover crops, conservation tillage, and narrow rows can suppress weed emergence and growth, subsequent chemical control measures are likely needed. Glyphosate has minimal environmental impact yet controls a broad spectrum of weeds and can be applied post-emergence in glyphosate-resistant *Z. mays* through the V8 growth stage (Ritchie et al., 1996) or when plants are 76 cm in height (Anonymous, 2003). However, the duration of weed control is sometimes not sufficient following a single glyphosate application, resulting in lower *Z. mays* yields compared with sequential glyphosate applications (Gower et al., 2002; Johnson et al., 2000). When glyphosate is applied soon after crop emergence, subsequent weed emergence can occur, whereas delaying glyphosate can lead to yield reductions from early season weed interference prior to application (Gower et al., 2002; Johnson et al., 2000). Because cover crops provide early season weed suppression, integration of cover crops with the use of glyphosate is likely to allow the glyphosate application to be delayed without yield loss from early season weed interference. In the mid-western United States, Tharp and Kells (2001a) found a *T. aestivum* cover crop controlled with glyphosate at *Z. mays* planting resulted in *Z. mays* grain yields similar to weed-free plots. Therefore, the objective of this research was to determine if a *Z. mays* production system including glyphosate, a cover crop, conservation tillage, and narrow row widths would result in weed control and *Z. mays* grain yields comparable to a traditional weed-control system that utilizes atrazine plus metolachlor in wide rows with conventional tillage.

2. Materials and methods

A field study was conducted at Clemson University's Pee Dee Research and Education Center located near Florence, SC, from November 2001 through *Z. mays* harvest in 2002 and from November 2002 through *Z. mays* harvest in 2003. The study was conducted to assess the potential for using small grain cover crops, narrow rows, conservation tillage, and glyphosate as a replacement for atrazine plus metolachlor in Southeastern *Z. mays* production. The experimental design was a randomized complete block with four replications. Experimental treatments included all combinations of surface tillage (tilled or none), row width (38 or 76 cm), and herbicide programme (atrazine at 1.68 kg ai/ha plus *S*-metolachlor at 1.68 kg ai/ha applied pre-emergence; glyphosate at 0.84 kg ae/ha applied at the V6–V7 *Z. mays* growth stage; or no herbicide) without a cover crop. Additional treatments included all combinations of cover crop (*T. aestivum* or *S. cereale*), row widths (38 or 76 cm), and herbicide programme (glyphosate at 0.84 kg/ha applied at the V6–V7 *Z. mays* growth stage or no herbicide) all without surface tillage for a total of 20 experimental treatments. Atrazine plus *S*-metolachlor was not applied to the *S. cereale* and *T. aestivum* cover crop treatments because the pre-emergence herbicides would mask any weed suppression due to the cover crop and this practice would not be readily adopted by producers.

The soil type in both years was a Goldsboro loamy sand (fine-loamy, siliceous, thermic Aquic Kandiudults). *G. max* was planted the year prior to test establishment in both years. 'Wrens Abruzzi' *S. cereale* and 'NK 9663' *T. aestivum* were no-till planted in 18-cm rows on November 15, 2002 and November 18, 2003 at a seeding rate of 67 and 112 kg/ha, respectively. Liquid fertilizer (25% nitrogen and 3.5% sulfur) was broadcast applied to the test area at a rate of 157 kg N/ha approximately 2 weeks prior to *Z. mays* planting. Plots assigned to be surface tilled were disked twice to a depth of 12 cm. After disking, the entire test area was broadcast deep tilled to a depth of 41 cm using a four-shanked ParaTill[1] equipped with a serrated cutting coulter mounted in front of each shank. 'AG 687 RR' *Z. mays* (glyphosate-resistant) was planted at 59,000 seed/ha in 38- and 76-cm-wide rows on April 9, 2002 and April 22, 2003. Wide- and narrow-row plots consisted of six and twelve 18.3-m-long rows, respectively. Glyphosate at 0.84 kg/ha was applied to all plots not having surface tillage, including the no herbicide treatments (in-crop), approximately 10 d before planting providing effective control of the cover crops and winter weeds, except *Oenothera laciniata* Hill. All herbicides were applied with a CO_2-pressurized backpack equipped with flat-fan nozzles calibrated to deliver a carrier volume of 187 L/ha (atrazine and *S*-metolachlor) and 94 L/ha (glyphosate).

The percentage of ground area covered by plant residues was estimated immediately following planting by placing two 7.6 m line transects across the plots and assessing the presence of plant residue every 0.3 m along the transect. The amount of plant residue in each treatment immediately following *Z. mays* planting was estimated by harvesting all plant residues on the soil surface from a 1 m^2 quadrat in each plot, oven-drying the residues at 60 C, and weighing. Because differences were noted in *Z. mays* growth between surface tilled and non-tilled plots at treatment with glyphosate, *Z. mays* density per 2-m row and growth stage (visible collars) of three plants per plot in four replications was determined (Table 1). Additionally, weed density from a 1 m^2 quadrat and weed height and leaf number of five plants of each species was recorded from random plots in each replication not receiving atrazine plus *S*-metolachlor. Plots were visually rated for weed control by species 15 wk after *Z. mays* emergence (WAE) on a scale of 0–100, with 0 = no control and 100 = complete control. Early season reduction in *Z. mays* growth in surface-tilled plots relative to non-surface-tilled plots was rated prior to the in-crop glyphosate application, with 0 = no biomass or stand reduction and 100 = no *Z. mays* biomass or complete stand loss. At 15 WAE, above-ground weed biomass was harvested from a 1 m^2 quadrat in each plot, oven-dried at 60 °C, and weighed. At harvest maturity, 40 *Z. mays* ears were hand harvested in 2002 and subsequently threshed to determine grain yield. Grain yield in 2003 was determined by machine harvesting each plot. Grain yields in both years were corrected to 15.5% moisture.

All data were analyzed as a single factor experiment using analysis of variance because cover crops were not included in conjunction with atrazine plus *S*-metolachlor. To homogenize variances, weed control and injury 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 among cover crop residues and early season weed suppression among cover crops were separated using Fisher's protected LSD test at $\alpha < 0.05$. Contrasts were constructed to assess late-season weed control, weed biomass, and *Z. mays* grain yield differences within herbicide programmes, cover crops, tillage systems, and row widths.

3. Results and discussion

3.1. Surface residues

The year by treatment interaction for groundcover covered by surface residues following planting was not

[1]Brigham Brothers, Inc., P.O. Box 3338, 705 East Slanton Rd., Lubbock, TX 79452.

Table 1
Average height, density, and leaf number of *Z. mays* and weeds present prior to a post-emergence glyphosate application in *Z. mays* near Florence, SC in 2002 and 2003

Year	Species	Density (plants/m^2)	Leaf number (no.)	Height (cm)
2002	*Z. mays* (surface tillage)	5.2	6–7	54
	Z. mays (no surface tillage)	5.3	6–7	72
	Ipomoea lacunosa	1.5	2	12
	Brachiaria platyphylla	0.5	3	5
	Senna obtusifolia	0.4	2	9
	Volunteer *Triticum aestivum*	0.8	3	12
2003	*Z. mays* (surface tillage)	5.3	6	53
	Z. mays (no surface tillage)	5.3	6	74
	I. lacunosa	1	1	5
	B. platyphylla	2	17	12
	Amaranthus palmeri	8	33	21
	Sida rhombifolia	1	8	10
	Mollugo verticillata	9	3	2
	Portulaca oleracea	2	35	6

significant, so data were pooled over years. Planting a *S. cereale* cover crop in the absence of surface tillage resulted in the greatest amount of surface residue, with an average of 75% coverage measured following *Z. mays* planting (Table 2). The *T. aestivum* cover crop without surface tillage treatment and the no-surface-tillage, no-cover-crop treatment produced similar percentages of groundcover, averaging from 51% to 55%. In the surface tilled treatment, plant residue coverage of the soil surface was only 3%. The greater amount of residue produced by the *S. cereale* cover crop compared with the *T. aestivum* cover crop reported here agree closely with biomass differences found for these cover crops in other research studies conducted on the southeastern Coastal Plain (Bauer and Reeves, 1999; Norsworthy, 2004). Treatment differences in the amount of plant residue on the soil surface were similar to the differences found for percentage of soil surface covered by plant residues (Table 2).

Table 2
Plant residue coverage of the soil surface immediately following *Z. mays* planting as influenced by surface tillage and cover crop[a]

Surface tillage	Cover crop	Groundcover (%)	Groundcover (kg/ha)
Disked	None	3 a	68 a
None	None	51 b	1184 b
None	*Triticum aestivum*	55 b	1100 b
None	*Secale cereale*	75 c	1800 c

[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.

3.2. *Z. mays* vigor/height

Visual differences in *Z. mays* growth among production systems were detected in both years. At 4 WAE, *Z. mays* plants in no-surface-tillage plots were more vigorous than those in surface-tilled plots, with visual estimates of reduction in biomass (stunting and reduced biomass) ranging from 14% to 39%, irrespective of row width or herbicide programme (data not shown). Height measurements revealed *Z. mays* in surface tilled plots was 18–21 cm shorter than *Z. mays* plants in plots having no surface tillage (Table 1). Conversely, density and growth stage were similar between surface- and no-tilled systems in both years (Table 1), indicating internodes were shorter in surface-tilled plots.

3.3. Early season weed suppression

Weed species found in the study 4 WAE in 2002 included *Ipomoea lacunosa*, *Brachiaria platyphylla*, *Senna obtusifolia*, and volunteer *T. aestivum*, with each of these species occurring at relatively low densities (Table 1). In 2003, the weed spectrum was more diverse and weeds were at higher densities and consisted of *I. lacunosa*, *B. platyphylla*, *Amaranthus palmeri*, *Sida rhombifolia*, *Mollugo verticillata* (L.), and *Portulaca oleracea* (L.).

Weed suppression prior to applying glyphosate in 2002 was not rated because of the sparse weed population; however, weed suppression in 2003 was rated prior to applying glyphosate to assess the contribution of each cover crop to early season weed control compared with the no-cover-crop/no-surface-tillage treatment. *A. palmeri*, *B. platyphylla*, and *Mollugo verticillata* control through 4 WAE in 2003 averaged 100% in all plots treated with atrazine plus *S*-metolachlor, whereas *I. lacunosa* was 94% when

Table 3
Influence of cover crop and surface tillage on control of *M. verticillata* (MOLVE), *A. palmeri* (AMAPA), *I. lacunosa* (IPOLA), and *B. platyphylla* (BRAPP) at 4 weeks after *Z. mays* emergence in non-herbicide-treated plots, averaged over *Z. mays* row width in 2003[a,b]

Surface tillage	Cover crop	MOLVE (%)	AMAPA (%)	IPOLA (%)	BRAPP (%)
Tilled	None	0 b	0 a	0 c	0 b
None	None	28 a	18 a	38 b	50 a
None	*T. aestivum*	5 ab	15 a	40 b	61 a
None	*S. cereale*	16 ab	18 a	65 a	59 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 based on transformed data. Percentage weed control data were arcsine square root transformed prior to analysis with non-transformed data shown.

[b]Weed control was visually estimated relative to surface-tilled, no-cover-crop plots.

averaged over surface-tillage systems and row widths (data not shown). Although the *S. cereale* cover crop resulted in greater groundcover after *Z. mays* planting compared with the *T. aestivum* and no-cover crop treatments, an advantage in early season weed control by *S. cereale* compared with *T. aestivum* was found only for *I. lacunosa* (Table 3). In the absence of surface tillage or herbicides, *Mollugo verticillata* control ranged from 5 to 28% while *A. palmeri* control was only 15–18% (Table 3). The *S. cereale* cover crop controlled *I. lacunosa* 65% at 4 WAE, whereas *B. platyphylla* control between cover crops was 50–61%.

At least a portion of the control in no-surface tillage plots may be attributed to lower weed emergence. *Mollugo verticillata* and *A. palmeri* have much smaller seeds than *I. lacunosa* or *B. platyphylla*. The small-seeded weeds may have been able to emergence in the no-surface-tillage plots since control of these weeds was generally similar between surface-tilled and no-surface-tillage treatments. Conversely, for large-seeded weeds such as *B. platyphylla* or *I. lacunosa*, burial through surface tillage likely increased emergence, thus control was increased with no surface tillage. These findings agree with those of Lovelace and Oliver (2000) for *I. lacunosa*, where emergence was increased at least two-fold with surface tillage compared with no surface tillage. Furthermore, large-seeded weeds exhibit a strong parabolic relationship with burial depth (Forcella et al., 2000). Thus, as reviewed by Buhler (1995), eliminating surface tillage generally reduces emergence of large-seeded, annual weeds, whereas small-seeded weeds that do not require burial are often adapted to systems that exclude surface tillage, which seems characteristic of *Mollugo verticillata* and *A. palmeri* in this study.

3.4. Late-season weed control and biomass production

The year by treatment interaction for late-season *I. lacunosa* and *B. platyphylla* control was not significant, so weed control data were pooled over years. Weed biomass differed between years; therefore, years are presented separately.

3.4.1. Herbicide programme

Atrazine plus *S*-metolachlor and glyphosate alone were effective in providing season-long control of all weed species, irrespective of cover crop, surface tillage, or row width (Table 4). Late-season control of all species with glyphosate ranged from 93% to 99% at 15 WAE, whereas atrazine plus *S*-metolachlor provided 90–100% control of the same spectrum. Weed control was similar between herbicide programmes for all species evaluated, except *A. palmeri* which was controlled 99% with glyphosate and 100% with atrazine plus *S*-metolachlor. Although significant, a difference of only 1% probably is of little biological importance. Thus, at the weed densities and for the spectrum

Table 4
Influence of herbicide programme, cover crop, surface tillage, and row width on control of *S. obtusifolia* (CASOB), *A. palmeri* (AMAPA), *S. rhombifolia* (SIDRH), *I. lacunosa* (IPOLA), and *B. platyphylla* (BRAPP) at 15 weeks after *Z. mays* emergence near Florence, SC in 2002 and 2003[a]

Treatment	CASOB	AMAPA	SIDRH	IPOLA	BRAPP
	2002	2003	2003		
Herbicide programme					
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
S. cereale	97 a	100 a	92 a	89 a	95 a
T. aestivum	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 of transformed data. Percentage weed control data were arcsine square root transformed prior to analysis with non-transformed data shown.

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

[c]*S. cereale* and *T. aestivum* 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 programme, cover crop, surface tillage, and row width on weed biomass at 15 weeks after *Z. mays* emergence and *Z. mays* grain yield near Florence, SC in 2002 and 2003[a]

Treatment	Weed biomass (g/m^2)		*Z. mays* grain yield (kg/ha)	
	2002	2003	2002	2003
Herbicide programme				
Glyphosate	9 b	12 b	7130 a	5720 a
Atrazine + *S*-metolachlor	13 b	17 b	6810 a	6140 a
Non-treated	28 a	171 a	6820 a	5120 b
Cover crop[b]				
None	24 a	107 a	6790 a	5580 a
S. cereale	17 a	57 b	7260 a	5160 a
T. aestivum	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 *S. cereale* and *T. aestivum* was not evaluated in combination with these herbicides.
[c]*S. cereale* and *T. aestivum* were excluded from the comparison of surface tillage verus no surface tillage because both cover crops were only present in no surface tillage treatments.

evaluated in these studies, a single post-emergence glyphosate application was just as effective as a pre-emergence application of atrazine plus *S*-metolachlor in terms of providing season-long weed control.

Weed biomass ranged from 9 to 12 g/m^2 in glyphosate-treated plots and 13–17 g/m^2 in the atrazine plus *S*-metolachlor plots in both years (Table 5). Conversely, weed biomass differed between years when no herbicide was applied, averaging 28 g/m^2 in 2002 and 171 g/m^2 in 2003. Year differences in biomass production when no herbicide was applied were probably due to a less dense weed population in 2002 than in 2003 (Table 1) and the occurrence of *A. palmeri* in the 2003 plots. Temperatures during summer months in the southeastern United States are conducive for rapid biomass accumulation by *A. palmeri* (Wright et al., 1999), with biomass production during summer months exceeding 300 g/m^2 at densities as low as 2 plants/m of *G. max* row (Klingaman and Oliver, 1994).

3.4.2. Cover crop

Neither the *S. cereale* nor *T. aestivum* cover crop improved late-season weed control in glyphosate-applied plots (Table 4). There was no weed control in the non-treated cover crop plots compared with the non-treated, non-cover-crop plots by 15 WAE, which is similar to the findings by Norsworthy (2004). Similarly, weed biomass was the same for each cover crop treatment in 2002. However, weed biomass in 2003 was almost two-fold less in the *S. cereale* cover crop treatment compared with the *T. aestivum* cover-crop or no-cover-crop treatment (Table 5).

3.4.3. Surface tillage

Late-season weed control was not influenced by surface tillage, except for *S. obtusifolia* where control was less in the surface-tilled plots (Table 4). This reduced control was mainly due to atrazine plus *S*-metolachlor providing only 67% control in the surface tilled/wide row/no-cover-crop treatment (data not shown). This decreased control may in part be due to greater *S. obtusifolia* emergence following surface tillage as Bararpour and Oliver (1998) showed *S. obtusifolia* densities to be approximately six-fold greater in surface-tilled plots than in no-surface-tillage plots. Differences in weed control and weed biomass between tillage systems were not likely to be detected since both herbicide programmes were highly efficacious.

3.4.4. Row width

I. lacunosa and *B. platyphylla* occurred in the test area both years with control of these weeds being similar between wide and narrow rows (Table 4). Similarly, weed biomass did not differ between row widths in both years of our study (Table 5). Others have shown that the effectiveness and consistency of herbicides is improved when *Z. mays* is planted using narrow row widths (Forcella et al., 1992; Teasdale, 1995) whereas others have failed to observe improved control (Johnson and Hoverstad, 2002). Since weed biomass was averaged over herbicide-treated and non-herbicide-treated plots and there was minimal biomass production following the post-emergence glyphosate application in both years, the similar weed biomass for the two row widths was probably due to the lack of early season weed control by either row width in non-herbicide-treated plots. Similar levels of early season weed control were expected since most weeds are likely to emerge prior to significant *Z. mays* canopy development in either row width. On the contrary, canopy differences may have developed shortly after glyphosate application (at the V7 growth stage), resulting in slight improvement in *S. obtusifolia* and *S. rhombifolia* control in narrow rows.

3.5. Z. mays grain yield

The year by treatment interaction for *Z. mays* grain yield was significant so years are presented separately.

Because of the low weed density in 2002 caused from the lack of rainfall throughout much of the growing season, grain yields were similar among all herbicide programmes, including the non-herbicide-treated check, ranging from 6820 to 7130 kg/ha (Table 5). In 2003, grain yields of the glyphosate and atrazine plus *S*-metolachlor treatments were similar due to the high level of weed control provided by both of these herbicide programs. Glyphosate and atrazine plus *S*-metolachlor treatments both had 500–1020 kg/ha higher grain yields than the non-herbicide treatments.

Use of a cover crop had no effect on grain yield either year, but grain yields differed between surface-tillage systems and row widths. Grain yields with no surface tillage averaged 400 and 310 kg/ha greater than grain yields found with surface tillage in 2002 and 2003, respectively. Even though *S. obtusifolia* control was less with surface tillage in 2002, the lower control likely had little influence on grain yield considering (1) the low weed population in 2002 (Table 1), (2) only slight differences in weed control between row widths (Table 5), and (3) the grain-yield similarities among herbicide-treated and non-herbicide-treated plots (Table 5). Rather, we attribute the lower grain yields of the surface-tilled plots to lower early season plant vigor, although the cause of the reduction in vigor is not known. Similar results have been found for *G. max* grown on Coastal Plain soils, where surface tillage caused 10–30% lower yields compared with *G. max* grown with no surface tillage (Frederick et al., 1998).

Narrowing the row width from 76 to 38 cm improved *Z. mays* grain yields an average of 1140 and 600 kg/ha in 2002 and 2003, respectively, which equates to a 10–15% average grain yield increase, similar to that observed by Murphy et al. (1996). Higher grain yields may be due to better light utilization of narrow-row *Z. mays* (Teasdale, 1995; Murphy et al., 1996; Tharp and Kells, 2001b) or faster canopy closure (Frederick, personal communication), even though narrowing the row width does not always improve light interception (Norsworthy and Oliveira, 2004; Westgate et al., 1997). Although weed control was improved by as much as 5% for some weed species by narrowing the row width, it is unlikely that these control differences contributed substantially to higher grain yields since weed populations were relatively low, especially in 2002.

A seeding rate of 59,000 seed/ha was chosen for our study because this is the seeding rate recommended for non-irrigated *Z. mays* production on the Coastal Plain when using wide row widths (Frederick, 1990) and because earlier research revealed increasing seeding rates further diminished grain-yield differences between wide and narrow rows (Frederick, personal communication). Furthermore, Coastal Plain soils with coarse texture and low organic carbon content are unlikely able to sustain good *Z. mays* growth at greater plant populations under periods of minimal rainfall (Frederick, 1990). Others have also observed an interaction between plant population and row width in terms of weed control and grain yield (DeSousa et al., 2003; Shrestha et al., 2001).

This research demonstrates that at a *Z. mays* population of approximately 59,000 plants/ha, post-emergence glyphosate application results in a level of weed control and grain yield equivalent to a pre-emergence application of atrazine plus *S*-metolachlor. Integration of a *S. cereale* or *T. aestivum* cover crop with glyphosate could aid early season weed suppression prior to the post-emergence glyphosate application, but have little or no effect on weed control after that time. Emergence of large-seeded weeds, such as *I. lacunosa*, may be diminished as surface tillage is eliminated, and narrow rows can improve weed control with glyphosate. In addition to the weed management benefits of these practices, conservation tillage and narrow rows can improve grain yields over traditional practices involving surface tillage and wide row widths.

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