Herbicide and Cover Crop Residue Integration for *Amaranthus* Control in Conservation Agriculture Cotton and Implications for Resistance Management

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Conservation agriculture (CA) practices are threatened by glyphosate-resistant Palmer amaranth. Integrated control practices including PRE herbicides and high-residue CA systems can decrease *Amaranthus* emergence. Field experiments were conducted from autumn 2006 through crop harvest in 2009 at two sites in Alabama to evaluate the effect of integrated weed management practices on *Amaranthus* population density and biomass, cotton yield, and economics in glyphosate-resistant cotton. Horizontal strips included four CA systems with three cereal rye cover crop seeding dates and a winter fallow (WF) CA system compared to a conventional tillage (CT) system. Additionally, vertical strips of four herbicide regimes consisted of: broadcast, banded, or no PRE applications of *S*-metolachlor (1.12 kg ai ha^{-1}) followed by (fb) glyphosate (1.12 kg ae ha^{-1}) applied POST fb layby applications of diuron (1.12 kg ai ha^{-1}) plus MSMA (2.24 kg ai ha^{-1}) or the LAYBY application alone. Early-season *Amaranthus* density was reduced in high-residue CA in comparison to the CA WF systems in 2 of 3 yr. *Amaranthus* densities in herbicide treatments that included a broadcast PRE application were lower at three of five sampling dates compared to banding early-season PRE applications; however, the differences were not significant during the late season and cotton yields were not affected by PRE placement. High-residue conservation tillage yields were 577 to 899 kg ha^{-1} more than CT, except at one site in 1 yr when CT treatment yields were higher. CA utilizing high-residue cover crops increased net returns over CT by \$100 ha^{-1} or more 2 out of 3 yr at both locations. High-residue cover crop integration into a CA system reduced *Amaranthus* density and increased yield over WF systems; the inclusion of a broadcast PRE application can increase early-season *Amaranthus* control and might provide additional control when glyphosate-resistant *Amaranthus* populations are present.

Nomenclature: Diuron; glyphosate; MSMA; *S*-metolachlor; Palmer amaranth, *Amaranthus palmeri* S. Wats.; cotton, *Gossypium hirsutum* L; rye, *Secale cereale* L.
Key words: Conservation tillage, pigweed, resistance management.

Las prácticas de agricultura de conservación (CA) están amenazadas por *Amaranthus palmeri* resistente al glifosato. Las prácticas integradas de control que incluyen herbicidas PRE y sistemas de CA con altos niveles de residuos, pueden disminuir la emergencia de A*maranthus.* Se llevaron a cabo experimentos de campo del otoño de 2006 hasta la cosecha del cultivo en 2009 en dos sitios en Alabama para evaluar el efecto de las prácticas integradas de manejo de malezas en la densidad de la población y la biomasa de *Amaranthus*, en el rendimiento del algodón y en lo económico, en algodón resistente a glyphosate. Bandas horizontales incluyeron cuatro sistemas CA: tres fechas de siembra de centeno como cultivo de cobertura y un sistema CA de barbecho de invierno (WF), comparados a un sistema de labranza convencional (CT). Adicionalmente, bandas verticales de cuatro regímenes de herbicidas, que consistieron en: aplicación general, aplicación en bandas o sin aplicaciones PRE de *S*-metolachlor (1.12 kg ia ha^{-1}), seguida de (fb) glyphosate (1.12 kg ea ha^{-1}) aplicado POST fb, aplicaciones layby de diuron (1.12 kg ia ha^{-1}) más MSMA (2.24 kg ia ha^{-1}) o solo la aplicación LAYBY. La densidad de *Amaranthus*, temprano en la temporada de crecimiento, se redujo en sistemas CA de altos residuos en comparación con los sistemas CA de WF en 2 de los 3 años. Las densidades de *Amaranthus* en tratamientos de herbicidas que incluyeron aplicaciones generales PRE fueron más bajas en tres de las cinco fechas de muestreo, comparadas a las aplicaciones PRE en banda temprano en la temporada; sin embargo, las diferencias no fueron significativas tarde en la temporada y los rendimientos del algodón no se vieron afectados por la ubicación de la aplicación PRE. Los rendimientos derivados de la labranza de conservación de altos residuos fueron de 577 a 899 Kg ha^{-1} más que CT, excepto en un sitio en un año cuando los rendimientos por tratamientos CT fueron más altos. Las prácticas CA utilizando cultivos de cobertura de altos residuos, incrementaron las utilidades netas por encima de la labranza convencional CT en \$100 ha^{-1} o más, en dos de los tres años en ambos sitios. La integración de un cultivo de cobertura de altos residuos en un sistema CA redujo la densidad de *Amaranthus* e incrementó el rendimiento por encima de los sistemas WF. La inclusión de una aplicación general PRE puede incrementar el control de *Amaranthus* temprano en la temporada y también puede proporcionar control adicional cuando hay poblaciones de *Amaranthus* resistentes a glyphosate presentes.

Conservation agriculture (CA) practices are threatened by the emergence and rapid spread of glyphosate-resistant Palmer amaranth. First identified in Georgia, it is currently reported widespread in Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, Missouri, North Carolina, South Carolina, and Tennessee. In addition, acetolactase synthase (ALS)-resistant Palmer amaranth is widely reported throughout the midsouth and southeast United States (Norsworthy et al. 2008; Webster 2005; Wise et al. 2009). Hundreds of thousands of CA hectares, some currently under U.S. Department of Agriculture (USDA), Natural Resources

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Conservation Service (NRCS) conservation program contracts, are at risk of being converted to higher-intensity tillage systems due to the inability to reliably control herbicide-resistant Palmer amaranth in CA systems, especially dryland systems. Currently, integration of high-residue cover crop systems, inversion of the soil profile and burial of the surface seedbank, and overlapping residual herbicides are increasingly being recommended by state cooperative extension systems (CES) throughout the Southeastern Coastal Plain and Midsouth Delta for herbicide-resistance management (Culpepper et al. 2011; Price et al. 2011a; Scott and Smith 2006). Surface tillage is also an increasing recommendation by CES to enable increased preplant-incorporated and PRE herbicide use and activity (Edmisten et al. 2010; Scott and Smith 2006; Steckel 2011). Between-row cultivation also is a proven method of controlling many troublesome and resistant weed species (Edmisten et al. 2010; UA 2006). However, conventional tillage (CT) practices decrease soil and water quality and might exclude producers from participating in government loan, insurance, and incentive programs designed to promote soil conservation stewardship. With the rapid spread of ALS- and glyphosate-resistant Palmer amaranth, the hectares in CA could, potentially, decline further without development of new, effective weed control strategies (Price et al. 2011b).

Recent resistant *Amaranthus* research and modeling efforts have focused on integrated weed management strategies to provide effective control, and reduce selection pressure for ALS and glyphosate resistance (Gustafson 2008; Neve et al. 2011; Norsworthy et al. 2011). Practices for use in integrated weed management systems include multiple cultural and chemical approaches. Recommendations for resistant *Amaranthus* management include: intensified crop rotation, cover cropping, delayed cotton planting, increased scouting, timely herbicide applications, diversified herbicide chemistries (including PRE herbicides), and inversion tillage (Price et al. 2011b). The implementation of integrated approaches utilizing practices such as these, however, has yet to be fully developed and adopted by producers.

To reduce the use of intensive tillage practices in integrated weed management systems for *Amaranthus* control, further evaluation of alternative control strategies is necessary. High-residue cover crops, which have been shown to provide early-season weed control, can be utilized in cotton along with other management tactics to suppress *Amaranthus* growth (Aulakh et al. 2011; Mirsky et al. 2011; Price et al. 2006, 2007, 2011a; Reeves et al. 2005; Ryan et al. 2011; Smith et al. 2011). Although early-season weed control is possible with cover crops, season-long control has required the use of herbicides (Reeves et al. 2005; Smith et al. 2011; Vasilakoglou et al. 2006; Yenish et al. 1996). Season-long weed control for *Amaranthus* is especially necessary due to its extended germination period (Bensch et al. 2003; Mitich 1997). POST-applied herbicides traditionally have provided this control; however, the need for diversified herbicide chemistries, as well as the need for residual weed control, necessitates the inclusion of PRE herbicides into a weed management system (Culpepper et al. 2007; Whitaker et al. 2011). Concerns regarding the efficacy of PRE herbicides used in conjunction with cover crops (due to interception and sorption) have led to the recommendation of, at a minimum, banded applications of PRE herbicides in CA systems to provide in-row residual weed control (Price et al. 2011a). Research is necessary to evaluate the integration of cover crops and this type of herbicide practice as an alternative to tillage for resistant *Amaranthus* control.

Little research has been conducted to determine the response of *Amaranthus* to integrated cover crops and various herbicide management practices. Moreover, the cost to producers to implement these strategies as an alternative to CT practices needs to be evaluated. Therefore, field experiments were conducted to determine *Amaranthus* density, biomass, and cotton yield, in a CA system (with four winter residue amounts) and a conventional system using four herbicide regimes. An economic analysis was performed to compare production costs and net returns for these treatments.

Material and Methods

Identical field experiments were established at the E. V. Smith Research and Extension Center located near Shorter, AL and at the Tennessee Valley Research and Extension Center near Bella Mina, AL in fall 2006. The experiment involved a cotton to corn (*Zea mays* L.) to cotton rotation with both phases of rotation present on adjoining fields. Thus, the experiment was established each fall from 2006 through 2008 following corn. The rotation was included to reflect a CES rotation recommendation for glyphosate-resistant Palmer amaranth management in the southeast to include corn as a rotational crop. Corn plots were managed uniformly according to CES recommendations in a conservation system that included a crimson clover (*Trifolium incarnatum* L.) cv. AU Robin cover crop and use of atrazine (AAtrex, Syngenta Crop Protection, LLC, Greensboro, NC) for *Amaranthus* control. Native glyphosate-susceptible populations of Palmer amaranth and redroot pigweed (*Amaranthus retroflexus* L.) were present, exclusive to almost all other weed species, at the E. V. Smith and Tennessee Valley locations, respectively. However, an additional 60,000 glyphosate-susceptible seed of each respective *Amaranthus* species were broadcast over the experimental area at each location in the fall of 2006 and again and 2007 following the corn rotation to assure an adequate seedbank preceding the cotton experiment. Glyphosate-susceptible seeds were utilized because glyphosate-resistant Palmer amaranth was not widely reported in Alabama at initiation of this experiment.

The soil types were a Compass loamy sand (coarse-loamy, siliceous, subactive, thermic Plinthic Paleudults) at E. V. Smith and a Decatur silty loam (fine, kaolinitic, thermic, Rhodic Paleudult) at Tennessee Valley. The CA treatments included three cereal rye (*Secale cereale* L. cv. 'Elbon') cover crop seeding dates each autumn, which include an early (PD 1), mid (PD 2), and late (PD 3) planting date, and a winter fallow (WF) system. A CT system typically used on the Southeastern Coastal Plain utilizing surface tillage was included for comparison. The cover crop planting dates were based on the 30-yr average date of the first 0 C freeze. The three planting dates for each location were on the first freeze,

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Table 1. Herbicide program and application rates.

Herbicide program	Herbicides	Rate
		kg ha^{-1}
HB 1	*S*-metolachlor[a] PRE broadcast fb glyphosate[b] POST fb diuron[c] + MSMA[d] LAYBY[e]	1.12 fb 1.12 fb 1.12 +2.24
HB 2	*S*-metolachlor PRE banded fb glyphosate POST fb diuron + MSMA LAYBY	1.12 fb 1.12 fb 1.12 +2.24
HB 3	glyphosate POST fb diuron + MSMA LAYBY	1.12 fb 1.12 +2.24
HB 4	diuron + MSMA LAYBY	1.12 + 2.24

[a] *S*-metolachlor, Dual Magnum®, Syngenta Crop Protection, LLC, Greensboro, NC.

[b] Glyphosate, Roundup Weathermax®, Monsanto Company, St. Louis, MO.

[c] Diuron, Direx®, DuPont™, E.I. du Pont de Nemours and Co., Wilmington, DE.

[d] MSMA, MSMA®, Drexel Chemical Company, Memphis, TN.

[e] LAYBY applied with 0.25% v/v nonionic surfactant.

and 2 and 4 wk prior to the average first freeze day. WF CA plots were kept weed-free utilizing glyphosate at 1.12 kg ae ha^{-1} applied as needed. Additionally, vertical strips consisted of four herbicide regimes (HB) which were: (1) PRE herbicide broadcast fb POST fb LAYBY; (2) PRE herbicides banded fb POST fb LAYBY; (3) POST herbicides fb LAYBY; and (4) LAYBY only (Table 1). This last herbicide treatment was considered to be the control because the LAYBY application did not affect *Amaranthus* control due to *Amaranthus* maturity at application. All surviving *Amaranthus* were hand-pulled in all plots just prior to harvest to facilitate mechanical harvest of plots.

For each location, treatments were arranged in a randomized complete block design ($r = 3$) with a split-block restriction on randomization. This design was chosen for practical reasons because it enabled efficient seeding of cover crops and application of herbicides. Five management treatments were assigned to the horizontal strips and four herbicide regimes to vertical strips. For each location by year combination, there were three different sizes of experimental units (Steel and Torrie 1980). The largest experimental unit, HB, equals one quarter of the block size; the second largest, tillage management or planting date (PD), equals one-fifth of the block size; and the smallest (HB × PD combinations) equals one-twentieth of the block size. This design also led to three different sources of experimental errors catering to each experimental unit. Depending on location, the smallest experimental unit (henceforth called plot) was 4 m wide and 8 m long with four rows of cotton at a 1 m row spacing.

Cereal rye cv. Elbon was established with a no-till drill at a seeding rate of 100 kg ha^{-1} in the autumn of each year. In the spring prior to termination, cover crop biomass samples were collected by clipping all aboveground plant parts close to the soil surface from one randomly selected 0.25 m^2 section in each plot. Plant material was dried at 60 C for 72 h and weighed. Rye was rolled with a mechanical roller crimper prior to glyphosate application as described by Ashford and Reeves (2003) to aid in termination and to provide a uniform mat of residue on the soil surface.

Because the central Alabama (E. V. Smith) site had a well-developed hardpan, the entire experimental area, including the CT treatments to eliminate the chance of a deep-tillage interaction, was in-row subsoiled prior to cotton planting with a narrow-shank parabolic subsoiler (Parabolic subsoiler, KMC, Tifton, GA) equipped with pneumatic tires to close the subsoil channel. This equipment minimally disturbed residue and soil in a 5-cm-wide planting zone. Two disking passes and one field cultivator pass were then performed in the CT plots. Cotton cultivar DPL444BG/RR was planted at Tennessee Valley each year, whereas ST5242BR was planted at E. V. Smith in 2007 and 2008, and ST4427RF was planted in 2009. Cotton was planted 3 wk after winter cover crop termination with a four-row planter equipped with row cleaners and double-disk openers that minimized residue disturbance within the row.

All aboveground *Amaranthus* biomass was harvested from two randomly selected 0.25 m^2 sections per plot at the cotton four-leaf growth stage prior to POST applications and just prior to LAYBY. *Amaranthus* samples were dried and weighed in a manner similar to the rye cover.

Before harvest, all cotton plants in a randomly selected 3 m section for each of the two center rows of each plot were counted. Seed cotton yield was determined by machine harvesting the middle two rows of each plot with a spindle picker.

Economic Analysis. A partial budgeting approach was used to calculate the net returns of each treatment. Net returns were equal to the revenue from cotton production, both from lint and seed, minus the costs associated with tillage, cover crop establishment/termination, planting, herbicide application, and processing costs. To calculate revenue, the price of cotton lint (\$1.15 kg^{-1}; NASS 2010) was multiplied by the percentage lint turnout (0.40) times the cotton yield plus the price of cottonseed (\$0.14 kg^{-1}; NASS 2010) times the kg of cottonseed per kg of cotton lint (0.72). The production costs differ between the two locations for the cover crop and winter fallow treatments because the site at E. V. Smith was subsoiled prior to cotton planting. Commodity prices and production costs from 2009 were used to control variability caused by changing market conditions between years (MSU 2010; UGA 2010).

Statistical Analysis. Data were analyzed using generalized linear mixed models methodology as implemented in PROC GLIMMIX (Statistical Analysis Systems®, version 9.2, SAS Institute, Inc., Cary, NC). Production system, herbicide system, and their interactions were considered fixed effects. Interaction of year, replications with herbicide system, and production system, and location were considered random effects. Effects and interactions were evaluated at $P = 0.10$.

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Table 2. Rye biomass and redroot pigweed (AMARE) density and dry biomass data at Tennessee Valley Research and Extension Center and Palmer amaranth (AMAPA) at E. V. Smith Research and Extension Center for 2007.

	Tennessee Valley					E. V. Smith				
	Early[a]			Late		Early			Late	
	Rye kg ha^{-1}	AMARE No. ha^{-1}	Dry biomass kg ha^{-1}	AMARE No. ha^{-1}	Dry biomass kg ha^{-1}	Rye kg ha^{-1}	AMAPA No. ha^{-1}	Dry biomass kg ha^{-1}	AMAPA No. ha^{-1}	Dry biomass kg ha^{-1}
System[b]										
PD 1	8,692	90,000	3	5,6685	173	8,434	210,000	59	60,000	716
PD 2	7,397	123,333	2	30,019	140	6,059	226,667	56	180,000	818
PD 3	6,435	493,333	16	176,741	94	4,177	226,667	25	170,000	701
CT	0	560,000	198	83,501	150	0	580,000	96	223,333	1,443
WF	0	1,073,333	274	133,333	179	0	796,667	86	496,667	1,128
LSD (0.10)	668	352,953	82	115824	NS[d]	954	299,895	62	166,989	NS
Herbicide[c]										
HB 1	4,505	352,000	56	45	7	3,734	304,000	20	197,333	263
HB 2	4,505	677,333	102	75	8	3,734	517,333	76	200,000	391
HB 3	4,505	373,333	113	90	5	3,734	472,000	60	229,333	338
HB 4	4,505	469,333	124	384,015	570	3,734	338,667	102	277,333	2,854
LSD (0.10)	NS	315,691	NS	103,596	155	NS	NS	56	NS	740

[a] At the cotton four-leaf growth stage prior to the POST application (Early), and prior to the LAYBY application (Late), all aboveground parts for all *Amaranthus* were harvested from two randomly selected 0.25 m^2 sections per plot.

[b] PD 1 corresponds to the conservation system with first cover crop planting date (4 wk prior to average frost); PD 2, the conservation system with second cover crop planting date (2 wk prior to average frost); PD 3, the conservation system with the third cover crop planting date (at average frost); CT, the conventional tillage system (disking + field cultivation); and WF, the winter fallow system.

[c] HB 1 = PRE broadcasted (*S*-metolachlor), then POST at four-Leaf (glyphosate) + LAYBY (diuron + MSMA); HB 2 = PRE banded (*S*-metolachlor), then POST at four-Leaf (glyphosate) + LAYBY (diuron + MSMA); HB 3 = No PRE, POST at four-Leaf (glyphosate) + LAYBY (diuron + MSMA); and HB 4 = No PRE, no POST, LAYBY (diuron + MSMA).

[d] NS indicates not significant.

Economic data were analyzed using PROC MIXED, and treatment means were compared using least significance difference (LSD). All economic tests were also evaluated at P = 0.10.

Results and Discussion

Cover Crop. There was a year and location effect for cover crop biomass; therefore, data are presented separately. Rye biomass levels for each of the CA treatment planting dates ranged from 5,881 to 9,419 kg ha^{-1} (PD 1), 7,397 to 8,807 kg ha^{-1} (PD 2), and 6,054 to 8,193 kg ha^{-1} (PD 3) at Tennessee Valley for the 3-yr study. Rye biomass levels at this site did not differ between planting dates except during 2007 where biomass levels increased based on early planting date (PD 1 > PD 2 > PD 3). Rye biomass collected at E. V. Smith ranged from 7,325 to 10,886 kg ha^{-1} (PD 1), 6,059 to 9,160 kg ha^{-1} (PD 2), and 4,177 to 6,142 kg ha^{-1} (PD 3) during the study. Generally, greatest biomass levels were observed with PD 1 residue, with declining residue levels with later planting dates. WF residue was negligible at both sites due to chemical fallow treatments. Each planting date for rye produced sufficient biomass for high-residue CA systems to provide ground cover and was consistent with biomass levels reported by previous research in the Southeast (Reberg-Horton et al. 2011; Reeves et al. 2005; Reiter et al. 2007).

***Amaranthus* Density and Dry Biomass.** There was a year and location effect for *Amaranthus* density and dry biomass; therefore, data are presented separately. The main effects of cover crop/tillage management and herbicide treatment significantly affected *Amaranthus* density, although the treatment interactions did not. In 2007, early-season redroot pigweed densities at Tennessee Valley were reduced by CA cover crop treatments (PD 1: 90,000 plants [pl] ha^{-1}; PD 2: 123,333 pl ha^{-1}) when compared to CT (560,000 pl ha^{-1}) and WF (1,073,333 pl ha^{-1}) (Table 2). Drought conditions prevented the early emergence of redroot pigweed at Tennessee Valley in 2008 (Table 3). In 2009 at Tennessee Valley, cover crops, regardless of planting date, reduced early redroot pigweed density by at least 75,000 pl ha^{-1} over WF, but did not significantly reduce density in comparison with CT (Table 4). These results agree with a recent cotton experiment in Georgia, where rye residue alone reduced glyphosate-resistant Palmer amaranth emergence by 94% in the row middle and 50% in the drill compared to systems with no cover or inversion tillage (Culpepper et al. 2010).

At E. V. Smith, early-season Palmer amaranth density was reduced by over 350,000 pl ha^{-1} by cover crops when compared to both CT and WF in 2007 (Table 2); cover crops (excluding PD 3) reduced Palmer amaranth density again in 2008 by 45,000 pl ha^{-1} or more compared to CT and WF (Table 3). In 2009, no early-season Palmer amaranth density differences were noted between the cover crop/tillage treatments at E. V. Smith (Table 4). The trend for reduced weed emergence under cover crop residue in comparison to WF systems is consistent with previous research and illustrates the potential to utilize cereal cover crops for early-season weed suppression of *Amaranthus* species when high residue levels are obtained (Mirsky et al. 2011; Price et al. 2006; Reeves et al. 2005; Saini et al. 2006).

Table 3. Rye biomass and redroot pigweed (AMARE) density and dry biomass data at Tennessee Valley Research and Extension Center and Palmer amaranth (AMAPA) at E. V. Smith Research and Extension Center for 2008.

	Tennessee Valley					E. V. Smith				
	Early[a]			Late		Early			Late	
	Rye kg ha^{-1}	AMARE No. ha^{-1}	Dry biomass kg ha^{-1}	AMARE No. ha^{-1}	Dry biomass kg ha^{-1}	Rye kg ha^{-1}	AMAPA No. ha^{-1}	Dry biomass kg ha^{-1}	AMAPA No. ha^{-1}	Dry biomass kg ha^{-1}
System[b]										
PD 1	9,419	0	0	1,1667	213	7,325	62,500	188	153,333	5,406
PD 2	8,807	0	0	6,667	40	7,701	23,333	92	131,667	4,362
PD 3	8,193	0	0	5,000	47	5,864	73,333	296	258,333	4,015
CT	0	0	0	28,333	203	0	107,500	709	351,667	6,564
WF	0	0	0	51,667	523	0	109,167	263	555,000	5,558
LSD (0.10)	1,591	0	0	39,799	434	1,199	35,248	271	214,219	NS[d]
Herbicide[c]										
HB 1	5,071	0	0	13,333	130	4,396	57,333	65	446,667	1,701
HB 2	5,958	0	0	6,667	48	4,210	90,000	270	290,667	1,977
HB 3	4,834	0	0	18,667	111	4,042	84,667	479	302,667	1,638
HB 4	5,272	0	0	44,000	533	4,065	68,667	426	120,000	15,407
LSD (0.10)	NS	0	0	35,597	388	NS	31,527	243	191,603	2,962

[a] At the cotton four-leaf growth stage prior to the POST application (Early), and prior to the LAYBY application (Late), all aboveground parts for all *Amaranthus* were harvested from two randomly selected 0.25 m^2 sections per plot.

[b] PD 1 corresponds to the conservation system with first cover crop planting date (4 wk prior to average frost); PD 2, the conservation system with second cover crop planting date (2 wk prior to average frost); PD 3, the conservation system with the third cover crop planting date (at average frost); CT, the conventional tillage system (disking + field cultivation); and WF, the winter fallow system.

[c] HB 1 = PRE broadcasted (*S*-metolachlor), then POST at four-Leaf (glyphosate) + LAYBY (diuron + MSMA); HB 2 = PRE banded (*S*-metolachlor), then POST at four-leaf (glyphosate) + LAYBY (diuron + MSMA); HB 3 = No PRE, POST at four-leaf (glyphosate) + LAYBY (diuron + MSMA); and HB 4 = No PRE, no POST, LAYBY (diuron + MSMA).

[d] NS indicates not significant.

For late-season redroot density at Tennessee Valley, PD 1 had reduced redroot pigweed over WF by 40,000 pl ha^{-1} in 2008 only (Table 3). For 2007 and 2009, no cover crop treatment reduced redroot pigweed counts over CT or WF. At E. V. Smith, Palmer amaranth density was reduced by PD 1 by over 435,000 pl ha^{-1} from WF treatments in 2007 (Table 2), reduced by PD 2 by 420,000 pl ha^{-1} in comparison to WF in 2008 (Table 3), and reduced by PD 1 by 80,000 pl ha^{-1} over WF in 2009 (Table 4). No reductions over CT were noted in any year. The rate of cover crop biomass decomposition has been shown to limit weed control achieved from cover crop use to early-season control (Masiunas et al. 1995; Mohler and Teasdale 1993). Because season-long control cannot generally be achieved with cover crops alone, surface and/or inversion tillage has been suggested as a means to control *Amaranthus* species, particularly in areas with high densities of glyphosate resistance (Price et al. 2011b). In this experiment, however, surface CT practices did not reduce *Amaranthus* densities further than cover crop treatments, likely due to insufficient seed burial. Cover crops also were able to suppress populations to a greater extent than fallow systems in most instances. These results suggest that high residue cover crops could be used without increased risk of elevated *Amaranthus* density over surface CT systems and also could achieve greater weed suppression than in WF systems. However, low residue cover crops resulting from late planting and/or drought might increase *Amaranthus* density.

For early-season redroot pigweed counts at Tennessee Valley, differences were variable between years. In 2007, PRE herbicide applications, both broadcast (HB 1) and banded (HB 2), were similar to POST only (HB 3 and 4) applications (Table 2). Furthermore, in 2007 HB 1 reduced pigweed densities by over 325,000 pl ha^{-1} in comparison to HB 2 (Table 2). Densities in 2009 were not different between PRE applications and POST + LAYBY; however, LAYBY-only treatments had 140,000 to 160,000 pl ha^{-1} more than the other treatments. Early-season Palmer amaranth density at E. V. Smith had measurable differences between treatments in 2 of the 3 yr of the study. In both 2008 and 2009, amaranth counts were reduced from HB 1 over HB 2 by 32,000 pl ha^{-1} and 252,000 pl ha^{-1}, respectively (Tables 3 and 4); similar results were noted in previous research that found broadcast PRE applications provided greater control of Palmer amaranth than banded applications (Toler et al. 2002).

Trends in late-season amaranth densities were different from measurements recorded earlier in the season. At Tennessee Valley, PRE herbicide treatments did not reduce density over the POST + LAYBY treatment (HB 3); in 2007 and 2009, LAYBY-only (HB 4) applications did, however, have increased redroot pigweed counts by over 384,000 and 144,000 pl ha^{-1} compared to other treatments (Table 2 and 4). No differences between broadcast and banded PRE herbicides were observed for late-season counts at Tennessee Valley for any year in the study. At E. V. Smith, late-season Palmer amaranth densities did not differ between herbicide treatments during 2007 (Table 2). Amaranth counts in 2008 showed little difference between PRE herbicide treatments and POST-only treatments; however, the LAYBY-only application did have reduced Palmer amaranth counts over treatments with broadcast PRE applications by 327,000 pl ha^{-1} (Table 3).

Table 4. Rye biomass and redroot pigweed (AMARE) density and dry biomass data at Tennessee Valley Research and Extension Center and Palmer amaranth (AMAPA) at E. V. Smith Research and Extension Center for 2009.

	Tennessee Valley					E. V. Smith				
	Early[a]			Late		Early			Late	
	Rye kg ha^{-1}	AMARE No. ha^{-1}	Dry biomass kg ha^{-1}	AMARE No. ha^{-1}	Dry biomass kg ha^{-1}	Rye kg ha^{-1}	AMAPA No. ha^{-1}	Dry biomass kg ha^{-1}	AMAPA No. ha^{-1}	Dry biomass kg ha^{-1}
System[b]										
PD 1	5,881	46,667	564	70,000	963	10,886	198,333	167	25,000	959
PD 2	7,554	78,333	609	26,667	512	9,160	158,333	183	33,333	1,732
PD 3	6,054	68,333	889	25,000	626	6,142	231,667	210	58,333	1,792
CT	0	50,000	47	18,333	465	0	393,333	410	31,667	2,344
WF	0	155,000	1,216	48,333	494	0	380,000	222	105,000	1,780
LSD (0.10)	1,703	75,891	449	NS[d]	NS	1,084	NS	130	76,606	NS
Herbicide[c]										
HB 1	3,843	29,333	334	0	0	5,282	101,333	61	0	0
HB 2	3,947	48,000	595	1,333	1	5,661	353,333	240	0	0
HB 3	4,161	50,667	551	2,667	13	5,265	325,333	408	0	0
HB 4	3,639	190,667	1,180	14,6667	2,433	4,743	309,333	244	202,667	6,885
LSD (0.10)	NS	67,879	401	46,946	847	NS	241,622	116	68,518	1,726

[a] At the cotton four-leaf growth stage prior to the POST application (Early), and prior to the LAYBY application (Late), all aboveground parts for all *Amaranthus* were harvested from two randomly selected 0.25 m^2 sections per plot.

[b] PD 1 corresponds to the conservation system with first cover crop planting date (4 wk prior to average frost); PD 2, the conservation system with second cover crop planting date (2 wk prior to average frost); PD 3, the conservation system with the third cover crop planting date (at average frost); CT, the conventional tillage system (disking + field cultivation); and WF, the winter fallow system.

[c] HB 1 = PRE broadcasted (*S*-metolachlor), then POST at four-leaf (glyphosate) + LAYBY (diuron + MSMA); HB 2 = PRE banded (*S*-metolachlor), then POST at four-leaf (glyphosate) + LAYBY (diuron + MSMA); HB 3 = No PRE, POST at four-leaf (glyphosate) + LAYBY (diuron + MSMA); and HB 4 = No PRE, no POST, LAYBY (diuron + MSMA).

[d] NS indicates not significant.

Differences in *Amaranthus* biomass were significant in several instances at both locations for cover crop treatments as well as herbicide treatments (Tables 2, 3, and 4). In general, as *Amaranthus* density increased, biomass increased. At Tennessee Valley in 2007, early season redroot pigweed biomass from cover crop treatments was significantly higher in CT (198 kg ha^{-1}) and WF (274 kg ha^{-1}) in comparison with PD 1 (3 kg ha^{-1}) and PD 2 (2 kg ha^{-1}). Similarly, early-season

Table 5. Seed cotton yield (kg ha^{-1}) for Tennessee Valley Research and Extension Center and E. V. Smith Research and Extension Center for 2007, 2008, and 2009 as affected by production system and herbicides.

	Tennessee Valley			E. V. Smith		
	2007	2008	2009	2007	2008	2009
	kg ha^{-1}					
System[a]						
PD 1	1,970	1,992	2,821	2,600	3,039	1,848
PD 2	2,172	1,577	2,855	2,490	2,591	1,933
PD 3	2,010	1,676	2,381	2,315	2,611	1,982
CT	1,370	2,683	2,244	1,701	2,399	2,106
WF	1,939	2,279	1,763	1,932	2,666	1,946
LSD (0.10)	365	404	327	424	556	NS[c]
Herbicide[b]						
HB 1	2,189	2,189	3,122	2,502	3,034	2,560
HB 2	2,142	2,451	3,007	2,598	3,038	2,419
HB 3	2,310	2,395	3,017	2,712	3,601	2,532
HB 4	928	1,129	506	1,018	972	341
LSD (0.10)	326	362	293	379	497	442

[a] PD 1 corresponds to the conservation system with first cover crop planting date (4 wk prior to average frost); PD 2, the conservation system with second cover crop planting date (2 wk prior to average frost); PD 3, the conservation system with the third cover crop planting date (at average frost); CT, the conventional tillage system (disking + field cultivation); and WF, the winter fallow system.

[b] HB 1 = PRE broadcasted (*S*-metolachlor), then POST at four-leaf (glyphosate) + LAYBY (diuron + MSMA); HB 2 = PRE banded (*S*-metolachlor), then POST at four-leaf (glyphosate) + LAYBY (diuron + MSMA); HB 3 = No PRE, POST at four-leaf (glyphosate) + LAYBY (diuron + MSMA); and HB 4 = No PRE, no POST, LAYBY (diuron + MSMA).

[c] NS indicates not significant.

Table 6. Costs for production system and herbicide treatments, and other production costs at Tennessee Valley Research and Extension Center and E. V. Smith Research and Extension Center.

System[a]	Production costs ($ ha^{-1}) E. V. Smith	Production costs ($ ha^{-1}) Tennessee Valley	Operations
CT	37.73		Heavy disk (×2), field cultivator, planter
PD1, PD2, PD3	182.59	170.8	Rye cover crop establishment and termination, subsoiler (EVS only), no-till planter
WF	57.01	45.22	Subsoiler (EVS only), no-till planter
Herbicide[b]	Production costs ($ ha^{-1})		Operations
HB 1	131.68		PRE broadcast, POST, LAYBY
HB 2	131.68		PRE banded, POST, LAYBY
HB 3	95.06		POST, LAYBY
HB 4	46.04		LAYBY
Other Production Costs			
Ginning	$0.17 kg^{-1} of cotton lint		
Storage	$10.50 cotton bale^{-1}		
Promotion	$5.77 cotton bale^{-1}		

[a] PD 1 corresponds to the conservation system with first cover crop planting date (4 wk prior to average frost); PD, the conservation system with second cover crop planting date (2 wk prior to average frost); PD 3, the conservation system with the third cover crop planting date (at average frost); CT, the conventional tillage system (disking + field cultivation); and WF, the winter fallow system.

[b] HB 1 = PRE broadcasted (*S*-metolachlor), then POST at four-leaf (glyphosate) + LAYBY (diuron + MSMA); HB 2 = PRE banded (*S*-metolachlor), then POST at four-leaf (glyphosate) + LAYBY (diuron + MSMA); HB 3 = No PRE, POST at four-leaf (glyphosate) + LAYBY (diuron + MSMA); and HB 4 = No PRE, no POST, LAYBY (diuron + MSMA).

Palmer amaranth biomass at E. V. Smith was greater in herbicide treatments HB 3 (479 kg ha^{-1}) and HB4 (426 kg ha^{-1}) than in treatment HB1 (65 kg ha^{-1}); both treatment HB 3 and HB 4 had increased Palmer amaranth plant density compared to treatment HB1 (Table 2). In a few instances, *Amaranthus* biomass decreased under increased plant populations. Late-season Palmer amaranth biomass weights at E. V. Smith in 2008 reflected decreased dry biomass in herbicide treatment HB 1 (1,701 kg ha^{-1}) when compared to treatment HB 4 (15,407 kg ha^{-1}) even though density was greater in treatment HB 1 (Table 3). Reduced biomass production in treatments with increased density likely might be attributed to intraspecific competition; however, further study would be required and was beyond the scope of this investigation (Firbank and Watkinson 1985).

Table 7. System and herbicide treatment effects on changes in net returns ($ ha^{-1}) from conventional tillage and LAYBY only herbicide control at Tennessee Valley Research and Extension Center and E. V. Smith Research and Extension Center for 2007, 2008, and 2009.

	Tennessee Valley			E. V. Smith		
	2007	2008	2009	2007	2008	2009
	$ ha^{-1}					
System[a]						
PD 1	146.33	−455.00	135.51	273.94	153.24	−265.04
PD 2	240.87	−648.37	151.44	222.73	−55.51	−225.51
PD 3	165.33	−602.25	−69.34	140.97	−46.02	−202.58
WF	257.58	−195.62	−231.68	88.09	104.86	−93.60
CT	0.00	0.00	0.00	0.00	0.00	0.00
LSD (0.10)	NS[c]	226.74	167.67	119.74	110.21	NS
Herbicide[b]						
1	501.90	408.40	1,133.41	606.01	875.20	948.58
2	480.15	530.38	1,079.70	650.39	877.10	882.79
3	594.85	600.95	1,120.87	740.47	1,176.23	971.92
4	0.00	0.00	0.00	0.00	0.00	0.00
LSD (0.10)	157.39	183.86	91.85	262.39	372.46	314.36

[a] PD 1 corresponds to the conservation system with first cover crop planting date (4 wk prior to average frost); PD 2, the conservation system with second cover crop planting date (2 wk prior to average frost); PD 3, the conservation system with the third cover crop planting date (at average frost); CT, the conventional tillage system (disking + field cultivation); and WF, the winter fallow system.

[b] 1 = PRE broadcasted (*S*-metolachlor), then POST at four-leaf (glyphosate) + LAYBY (diuron + MSMA); 2 = PRE banded (*S*-metolachlor), then POST at four-leaf (glyphosate) + LAYBY (diuron + MSMA); 3 = No PRE, POST at four-leaf (glyphosate) + LAYBY (diuron + MSMA); and 4 = No PRE, no POST, LAYBY (diuron + MSMA).

[c] NS indicates not significant.

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Cotton Stand and Yield. There was a year and location effect for yield; therefore, data are presented separately. Cotton stand was not different for any cover crop management and herbicide treatment or interaction (data not shown). Interactions between tillage/cover crop management treatments and herbicide treatments were not significant for yield in the study. In tillage management treatments, the earliest cover crop seeding date (PD 1) out-yielded CT 2 of 3 yr at both Tennessee Valley and E. V. Smith. In 2007 and 2009 at Tennessee Valley, cotton yields for PD 1 were 600 kg ha^{-1} and 500 kg ha^{-1} higher than CT, respectively (Table 5). Yields at E. V. Smith were greater in PD 1 over CT by 900 kg ha^{-1} in 2007 and 600 kg ha^{-1} in 2008. Variable yield differences were noted between WF and PD treatments with yields generally not significantly different or slightly lower in WF. Previous research also has reported similar cotton yields following cover crops (Molin 2006; Schomberg et al. 2006; Schwab et al. 2002). In general, yield differences between herbicide treatments HB 1, HB 2, and HB 3 were not significant at either site. The lack of a yield difference between treatments HB1, HB 2, and HB 3, in light of differences between early-season weed densities, would indicate that POST herbicide applications of glyphosate in all treatments were effective in controlling *Amaranthus* before substantial yield loss occurred, as noted in HB 4 treatments (LAYBY only). However, it is unclear how yield would be affected in this study by broadcast or banded PRE applications in the presence of noncontrolled glyphosate-resistant *Amaranthus*; yield loss likely would occur when glyphosate-resistant pigweed were present.

Economic Analysis. There was a year and location effect for yield and subsequent net returns; therefore, data are presented separately. Table 6 lists production costs associated with treatments in this study. Changes in net returns due to treatment effects of tillage/cover crop treatments and herbicide treatments at E. V. Smith and Tennessee Valley are listed in Table 7. At E. V. Smith, the tillage/cover crop management systems had a significant impact on net returns in 2007 and 2008. Net returns were significantly less for WF and CT in 2007. The net returns to PD 1 were 44.25% and 18% greater than the net returns to CT in 2007 and 2008, respectively. In 2007 and 2008, even though CT had the lowest tillage/cover crop production costs, the yield increase from CT to PD 1 was large enough to more than cover the \$144.86 ha^{-1} increase in production costs associated with the rye cover crop establishment and termination. In 2008, net returns for PD 2 and PD 3 were similar to net returns for CT, further demonstrating that the yield increase from the use of a winter cover crop covers the additional production costs.

There was no significant interaction ($P \leq 0.10$) between the tillage/cover crop regimes and the herbicide treatments, except at Tennessee Valley in 2008 (data not shown). At Tennessee Valley, the tillage/cover crop management systems had a significant impact on net returns in 2008 and 2009. The CT treatment had the highest net return in 2008 and was significantly different from the three cover-crop (PD 1, PD 2, and PD 3) treatments. Seed cotton yields were significantly lower for the three cover-crop treatments than for the CT treatment, which reduced PD net returns when combined with higher production costs. In 2009, WF net returns were reduced over CT due to reduced cotton yields in this treatment.

At Tennessee Valley, net returns for herbicide treatments HB 1, HB 2, and HB 3 were not significantly different from each other at $P \leq 0.10$ (Table 7). In 2009 at E. V. Smith, the net returns for herbicide treatment three were significantly greater than herbicide treatments one and two at $P \leq 0.10$. Net returns were not significantly different between a broadcast PRE herbicide (HB 1) and banded PRE herbicide application (HB 2) in any year. This follows the results for seed cotton yields. The production costs were similar between the two treatments, and the difference between the average seed cotton yields was between 4 and 262 kg ha^{-1}.

The use of a high-residue cereal cover crop in cotton production potentially can aid in early-season *Amaranthus* suppression compared to WF systems. Based on *Amaranthus* density, the use of a broadcast PRE application could offer better weed control in high-residue CA cotton compared to banded applications when managing herbicide-resistant *Amaranthus*. Future CA research needs include evaluating *Amaranthus* density when varying within and between row residue disturbance and PRE herbicide placement. Traditional and alternative weed control strategies, such as the integration of high residue cereal cover crops in conjunction with effective herbicide programs, are necessary in order to sustain CA practices. The ongoing evaluation of weed management options suggests that control of herbicide-resistant Palmer amaranth might be achieved while protecting soil resources; however, it will require the use of diverse management tactics.

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Literature Cited

Ashford, D. L. and D. W. Reeves. 2003. Use of a mechanical roller-crimper as an alternative kill method for cover crops. Am. J. Altern. Agric. 18:37–45.

Aulakh, J. S., A. J. Price, and K. S. Balkcom. 2011. Weed management and cotton yield under two row spacings, conventional and conservation tillage systems utilizing conventional, glufosinate-, and glyphosate-based weed management systems. Weed Technol. 25:542–547.

Bensch, C. N., M. J. Horak, and D. Peterson. 2003. Interference of redroot pigweed (*Amaranthus retroflexus*), Palmer amaranth (*Amaranthus palmeri*), and common waterhemp (*A. rudis*) in soybean. Weed Sci. 51:37–43.

Culpepper, A. S. 2006. Glyphosate-induced weed shifts. Weed Technol. 20:277–281.

Culpepper, S., J. Kichler, and L. Sosnoskie. 2011. University of Georgia Programs for Controlling Moderate to Severe Populations of Glyphosate-Resistant Palmer Amaranth in 2011 Cotton. http://mulch.cropsoil.uga.edu/weedsci/HomepageFiles/Palmerhandout-2011.pdf. Accessed: March 7, 2011.

Culpepper, A. S., J. Kichler, L. Sosnoskie, A. York, D. Sammons, and R. Nichols. 2010. Integrating cover crop residue and moldboard plowing into glyphosate-resistant Palmer amaranth management programs, Page 1531 *in* Proceedings of Beltwide Cotton Conference. New Orleans, LA: National Cotton Council of America.

Culpepper, A. S., A. C. York, A. W. MacRae, J. Kichler, J. Whitaker, and A. L. Davis. 2007. Managing glyphosate-resistant Palmer amaranth in conventional and strip-till Roundup Ready cotton. Pages 1230–1231. *In* Proceedings of the Beltwide Cotton Conference. Memphis, TN: National Cotton Council of America.

Edmisten, K. L., F. H. Yelverton, J. F. Spears, D. T. Bowman, J. S. Bacheler, S. R. Koenning, C. R. Crozier, A. D. Meijer, and A. S. Culpepper. 2010. 2010 Cotton Information. NCSU Cooperative Extension Publication. http://ipm.ncsu.edu/Production_Guides/Cotton/contents.pdf. Accessed: March 7, 2011.

Firbank, L. G. and A. R. Watkinson. 1985. On the analysis of competition within two species mixtures of plants. J. Appl. Ecol. 22:503–517.

Gustafson, D. I. 2008. Sustainable use of glyphosate in North American cropping systems. Pest Manag. Sci. 64:409–416.

Masiunas, J. B., L. A. Weston, and S. C. Weller. 1995. The impact of rye cover crops on weed populations in a tomato cropping system. Weed Sci. 43:318–323.

Mirsky, S. B., W. S. Curran, D. M. Mortensen, M. R. Ryan, and D. L. Shumway. 2011. Timing of cover crop management effects on seed suppression in no-till planted soybean using a roller-crimper. Weed Sci. 59:380–389.

[MSU] Mississippi State University. 2010. Cotton 2010 Planning Budgets. Department of Agricultural Economics, Mississippi State University. Budget Report 2009–02. http://www.agecon.msstate.edu/what/farm/budget/pdf/10/MSUCOT10.pdf. Accessed: February, 2010.

Mitich, L. W. 1997. Redroot pigweed (*Amaranthus retroflexus*). Weed Technol. 11:199–202.

Mohler, C. L. and J. R. Teasdale. 1993. Response of weed emergence to rate of *Vicia villosa* Roth and *Secale cereale* L. residue. Weed Res. 33:487–499.

Molin, W. T. 2006. Contributions of tillage, rye cover crop and herbicide programs to weed control in glyphosate-tolerant cotton. Pages 171–173 *in* R. C. Schwartz, R. L. Baumhardt and J. M. Bell, eds. Proceedings of the 28th Southern Conservation Tillage Systems Conference. Bushland, TX.

[NASS] National Agricultural Statistics Service. 2010. Quick Stats. United States Department of Agriculture, Washington, DC. http://quickstats.nass.usda.gov/. Accessed: July, 2010.

Neve, P., J. K. Norsworthy, K. L. Smith, and I. A. Zelaya. 2011. Modeling glyphosate resistance management strategies for Palmer amaranth (*Amaranthus palmeri*) in cotton. Weed Technol. 25:335–343.

Norsworthy, J. K., M. McClelland, G. Griffith, S. K. Bangarwa, and J. Still. 2011. Evaluation of cereal and Brassicaceae cover crops in conservation-tillage, enhanced, glyphosate-resistant cotton. Weed Technol. 25:6–13.

Norsworthy, J. K., R. C. Scott, K. L. Smith, and L. R. Oliver. 2008. Response of northeastern Arkansas Palmer amaranth (*Amaranthus palmeri*) accessions to glyphosate. Weed Technol. 22:408–413.

Price, A. J., K. S. Balkcom, S. A. Culpepper, J. A. Kelton, R. L. Nichols, and H. Schomberg. 2011b. Glyphosate-resistant Palmer amaranth: a threat to conservation agriculture. J. Soil Water Conserv. 66:265–275.

Price, A. J., K. S. Balkcom, R. L. Raper, C. D. Monks, R. M. Barentine, and K. V. Iversen. 2011a. Controlling Glyphosate-Resistant Pigweed in Conservation Tillage Cotton Systems. Special Publication 09. http://www.ars.usda.gov/SP2UserFiles/Place/64200500/csr/SpecialPubs/SP09.pdf. Accessed: March 7, 2011.

Price, A. J., D. W. Reeves, and M. G. Patterson. 2006. Evaluation of weed control provided by three winter cereals in conservation-tillage soybean. Renewable Agric. Food Sys. 21:159–164.

Price, A. J., D. W. Reeves, M. G. Patterson, B. E. Gamble, K. S. Balkcom, F. J. Arriaga, and C. D. Monks. 2007. Weed control in peanut in a high residue conservation-tillage system. Peanut Sci. 34:59–64.

Reberg-Horton, S. C., J. M. Grossman, T. S. Kornecki, A. D. Meijer, A. J. Price, G. T. Place, and T. M. Webster. 2011. Utilizing cover crop mulches to reduce tillage in organic systems in the Southeast. Renewable Agric. Food Sys. 27:41–48. http://journals.cambridge.org/repo_A840SJ3h. Accessed: January 4, 2012.

Reeves, D. W., A. J. Price, and M. G. Patterson. 2005. Evaluation of three winter cereals for weed control in conservation-tillage non-transgenic cotton. Weed Technol. 19:731–736.

Reiter, M. S., D. W. Reeves, C. H. Burmester, and H. A. Torbert. 2007. Cotton nitrogen management in a high-residue conservation system: cover crop fertilization. Soil Sci. Soc. Am. J. 72:1321–1329.

Ryan, M. R., W. S. Curran, A. M. Grantham, L. K. Hunsberger, S. B. Mirsky, D. A. Mortensen, E. A. Nord, and D. O. Wilson. 2011. Effects of seeding rate and poultry litter on weed suppression from a rolled cereal rye cover crop. Weed Sci. 59:438–444.

Saini, M., A. J. Price, and E. van Santen. 2006. Cover crop residue effects on early-season weed establishment in a conservation-tillage corn-cotton rotation. Pages 175–178 *in* R. C. Schwartz, R. L. Baumhardt and J. M. Bell, eds. Proceedings of the 28th Southern Conservation Tillage Systems Conference. Bushland, TX.

Schomberg, H. H., R. G. McDaniel, E. Mallard, D. M. Endale, D. S. Fisher, and M. L. Cabrera. 2006. Conservation tillage and cover crop influences on cotton production on a southeastern U.S. Coastal Plain soil. Agron. J. 98:1247–1256.

Schwab, E. B., D. W. Reeves, C. H. Burmester, and R. L. Raper. 2002. Conservation tillage systems for cotton in the Tennessee Valley. Soil Sci. Soc. Am. J. 66:569–577.

Scott, R. C. and K. Smith. 2006. Prevention and Control of Glyphosate-Resistant Pigweed in Roundup Ready™ Soybean and Cotton. University of Arkansas Cooperative Extension Fact Sheet FSA2152. http://www.uaex.edu/Other_Areas/publications/PDF/FSA-2152.pdf. Accessed: March 7, 2011.

Smith, A. N., S. C. Reberg-Horton, G. T. Place, A. D. Meijer, C. Arellano, and J. P. Mueller. 2011. Rolled rye mulch for weed suppression in organic no-tillage soybeans. Weed Sci 59:224–231.

Steckel, L. 2011. 2011 Weed Control Manual for Tennessee. University of Tennessee Cooperative Extension Fact Sheet 1580. http://weeds.utk.edu/WeedTemplate_files/WeedControlManual/FINAL%20COMPLETE%20DRAFT.pdf. Accessed: March 7, 2011.

Steel, R.G.D. and J. H. Torrie. 1980. Principles and procedures of statistics, a biometrical approach. Tokyo, Japan: McGraw-Hill Kogakusha, Ltd. 633 p.

Toler, J. E., E. C. Murdock, and A. Keeton. 2002. Weed management systems for cotton (*Gossypium hirsutum*) with reduced tillage. Weed Technol. 16:773–780.

[UA] University of Arkansas. 2006. Herbicide Resistance: A Growing Problem in Arkansas. University of Arkansas Cooperative Extension Publication. http://www.aragriculture.org/weeds/herbicide_resistance.pdf. Accessed: March 7, 2011.

[UGA] University of Georgia. 2010. Cotton 2010 Conventional Tillage, Non-Irrigated Budget. Extension Agricultural and Applied Economics, University of Georgia. http://www.ces.uga.edu/Agriculture/agecon/printedbudgets.htm. Accessed: February, 2010.

Vasilakoglou, I., I. Dhima, I. Eleftherohorinos, and A. Lithourgidis. 2006. Winter cereal cover crop mulches and inter-row cultivation effects on cotton development and grass suppression. Agron. J. 98:1290–1297.

Webster, T. M. 2005. Weed survey—southern states: broadleaf crops subsection. Proc. South. Weed Sci. Soc. 58:291–304.

Whitaker, J. R., A. C. York, D. L. Jordan, and A. S. Culpepper. 2011. Weed management with glyphosate- and glufosinate-based systems in PHY 485 WRF cotton. Weed Technol. 25:183–191.

Wise, A. M., T. L. Grey, E. P. Prostko, W. K. Vencill, and T. M. Webster. 2009. Establishing the geographical distribution and level of acetolactate synthase resistance of palmer amaranth (*Amaranthus palmeri*) accessions in Georgia. Weed Technol. 23:214–220.

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.

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