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Diuron; fomesafen; glyphosate; monosodium methanearsonate; pendimethalin; carpetweed; *Mollugo verticillata* L. MOVE; common purslane; *Portulaca oleracea* L. POOL; large crabgrass; *Digitaria sanguinalis* (L.) Scop. DISA; Palmer amaranth; *Amaranthus palmeri* S. Watson AMPA; sicklepod; Senna obtusifolia (L.) Irwin & Barneby SEOB4; tall morning-glory *Ipomoea purpurea* (L.) Roth IPPU2; yellow nutsedge; *Cyperus esculentus* L. CYES; cereal rye; *Secale cereal* L.; cotton; *Gossypium hirsutum* L.

Keywords:
Conservation tillage; integrated weed management; Palmer amaranth; resistance management

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Effect of cover-crop biomass, strip-tillage residue disturbance width, and PRE herbicide placement on cotton weed control, yield, and economics

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Abstract

Conservation tillage adoption continues to be threatened by glyphosate and acetolactate synthase–resistant Palmer amaranth and other troublesome weeds. Field experiments were conducted from autumn 2010 through crop harvest in 2013 at two locations in Alabama to evaluate the effect of integrated management practices on weed control and seed cotton yield in glyphosate-resistant cotton. The effects of a cereal rye cover crop using high- or low-biomass residue, followed by wide or narrow within-row strip tillage and three PRE herbicide regimens were evaluated. The three PRE regimens were (1) pendimethalin at 0.84 kg ae ha^{-1} plus fomesafen at 0.28 kg ai ha^{-1} applied broadcast, (2) pendimethalin plus fomesafen applied banded on the row, or (3) no PRE. Each PRE treatment was followed by (fb) glyphosate (1.12 kg ae ha^{-1}) applied POST fb layby applications of diuron (1.12 kg ai ha^{-1}) plus monosodium methanearsonate (2.24 kg ai ha^{-1}). Low-residue plots ranged in biomass from 85 to 464 kg ha^{-1}, and high-biomass residue plots ranged from 3,119 to 6,929 kg ha^{-1}. In most comparisons, surface disturbance width, residue amount, and soil-applied herbicide placement did not influence within-row weed control; however, broadcast PRE resulted in increased carpetweed, large crabgrass, Palmer amaranth, tall morning-glory, and yellow nutsedge weed control in row middles compared with plots receiving banded PRE. In addition, high-residue plots had increased carpetweed, common purslane, large crabgrass, Palmer amaranth, sicklepod, and tall morning-glory weed control between rows. Use of banded PRE herbicides resulted in equivalent yield and revenue in four of six comparisons compared with those with broadcast PRE herbicide application; however, this would likely result in many between-row weed escapes. Thus, conservation tillage cotton would benefit from broadcast soil-applied herbicide applications regardless of residue amount and tillage width when infested with Palmer amaranth and other troublesome weed species.

Introduction

Conservation tillage practices are increasingly threatened and, in some cases, have been abandoned because of lack of control of glyphosate-resistant Palmer amaranth and glyphosate-resistant horseweed (*Conyza canadensis* L. Cronquist) (Price et al. 2011, 2016a). First identified in 2005 in Georgia, glyphosate-resistant Palmer amaranth is now reported extensively throughout the High Plains, Midsouth and Southeast cotton-producing states (Culpepper et al. 2006; Van Wychen 2016). Acetolactate synthase–resistant Palmer amaranth is also widely reported (Norsworthy et al. 2008; Van Wychen 2016; Webster 2005; Wise et al. 2009). Predicting our current situation, Ball (1992) recognized that reduced tillage accelerates additions to seedbanks of noncontrolled weeds, thus maintaining weed control in reduced-tillage systems is imperative. Ball also stated it is likely development of herbicide-resistant weeds will occur more rapidly in reduced-tillage systems because of potential rapid seedbank increases. In addition to crabgrass (*Digitaria* spp.), goosegrass [*Eleusine indica* (L.) Gaertn.], morning-glory (*Ipomoea* spp.), nutsedge (*Cyperus* spp.), Palmer amaranth, and sicklepod are the highly ranked troublesome weeds in cotton production (Van Wychen 2016). Full-season management strategies for Palmer amaranth, grasses, and nutsedge control are especially necessary because of their season-long germination (Bensch et al. 2003; Webster and Coble 1997; Webster et al. 2003). Glyphosate-based POST-only herbicide systems once provided adequate weed control; however, current challenges necessitate the inclusion of PRE herbicides into cotton weed management systems (Cahoon and York 2019; Culpepper et al. 2007, 2020; Whitaker et al. 2011).

In conservation tillage systems, use of high-biomass cover crops, overlapping residual herbicides, and, in extreme cases, strategic inversion tillage to bury shallow-germinating weed seeds such as Palmer amaranth are being recommended by state cooperative extension systems for control of herbicide-resistant and troublesome weeds to regain adequate weed control (Cahoon and York 2019; Culpepper et al. 2020; Price et al. 2011, 2016a; Smith et al. 2019). High-biomass winter cover crops, especially cereal cover crops preceding broadleaf cash crops, provide early-season weed suppression and are increasingly used with other weed management tactics for integrated weed control (Aulakh et al. 2011, 2012, 2015; Hand et al. 2019; Loux et al. 2017; Mirsky et al. 2011; Norsworthy et al. 2011; Palhano et al. 2017; Price et al. 2006, 2007, 2011, 2016b; Reeves et al. 2005; Ryan et al. 2011; Smith et al. 2011).

In addition, many producers in areas with coastal plain (including sands and sandy loams) or upland soils (clays or clay loams) use strip tillage to disrupt naturally occurring, annual, root-restricting hardpans. Strip-tillage surface residue disturbance width varies depending on equipment design and function. Thus, producers using a wide (30 cm row^{-1}) strip-tillage implement that disturbs more cover crop residue and soil may find increased weed seed germination. The effect of residue disturbance due to strip-tillage width on subsequent weed management has not been evaluated to our knowledge.

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 conservation tillage systems to provide in-row residual weed control (Banks and Robinson 1982; Hand et al. 2019; Potter et al. 2008). However, little research exists evaluating banded versus broadcast PRE applications in high-biomass reduced tillage systems. Even in high-residue conservation systems (>4.0 megaton ha^{-1} biomass) following rolling/crimping, soil in-row middles can be observed (A.J. Price, personal communication).

If PRE herbicides are only banded in strip-tilled rows, exposed soil in row-middle areas are likely sites for weed seed germination. With widespread acetolactate synthase– and glyphosate-resistant Palmer amaranth and other troublesome weeds, conservation tillage hectares will decline without development of effective management strategies (Price et al. 2011). Therefore, field studies were conducted to determine weed control, cotton population and yield, and revenue after testing two levels of cover-crop biomass, two residue-disturbance widths, and PRE herbicide treatments, either banded or broadcast.

Material and Methods

Experimental Design and Treatments

Identical field experiments were established at the E.V. Smith Research and Extension Center (EVS) located near Shorter, AL, and at the Wiregrass Research and Extension Center (WGS) near Headland, AL, in fall 2010, 2011, and 2012. The soil types were a Compass loamy sand (coarse-loamy, siliceous, subactive, thermic Plinthic Paleudults) at EVS, and a Dothan fine, sandy loam (fine-loamy, kaolinitic, thermic Plinthic Kandiudults) at WGS. The experimental design was a randomized complete block with 12 treatments in a factorial arrangement replicated four times for three years at each location (6 site-years total). Factor 1 was low or high biomass levels of cereal rye cv. Wrens Abuzzi. Cereal rye was established in the autumn of each year with a no-till drill in 17.8-cm rows at a seeding rate of 100 kg ha^{-1} and managed through fertilization and termination timing to attain the biomass levels. Cereal rye was planted at EVS on November 3, 2010; November 7, 2011; and November 6, 2012; and at WGS on November 23, 2010; November 23, 2011; and December 6, 2012. To attain a low biomass, plots received no nitrogen and rye was terminated approximately 8 weeks prior to cotton planting; thus, little residue was present at the time of cotton planting. High biomass was attained by fertilizing with a split application of nitrogen and sulfur at 34 and 12 kg ha^{-1}, respectively, applied in the fall at emergence and at the same rate in January, and delaying cover crop termination until approximately 2 weeks prior to cotton planting. Factor 2 was strip-till width treatments of (1) subsoiling with a wide residue disturbance (30 cm row^{-1}) 4-row 3-m KMC® Generation 1, 16 Series rip/strip till implement (Kelly Manufacturing Co., Tifton, GA) equipped with two wavy coulters and rolling baskets (Figure 1); or (2) or a narrow residue disturbance (<5 cm row^{-1}) with a 4-row 3-m KMC® Generation 2 subsoiler/leveler implement equipped with two pneumatic tires and hard rubber rollers (Figure 2). Factor 3 was three herbicide treatments of (1) pendimethalin (Prowl 3.3EC; BASF Crop Protection, Durham, NC) at 0.84 kg ae/ha^{-1} plus fomesafen (Reflex 2L; Syngenta Crop Protection, Greensboro, NC) at 0.28 kg ai/ha^{-1} applied PRE broadcast; (2) pendimethalin plus fomesafen applied PRE at the same rates banded on the row; or (3) no PRE. After early-season weed control rating, each of these three herbicide treatments was followed by (fb) glyphosate (Roundup Powermax 4.5EC; Monsanto, St. Louis, MO) at 1.12 kg ae ha^{-1} applied POST fb a layby applications of diuron (Diuron 4L; Drexel Chemical Co., Memphis, TN) at 1.12 kg ai ha^{-1} plus monosodium methanearsonate (MSMS 6 Plus 6L; Drexel Chemical Co.) at 2.24 kg ai ha^{-1} applied POST directed to approximately 40cm cotton.

Cover-Crop Sampling, Cotton Management, and Weed Control Assessment

In the spring prior to termination, cover-crop biomass samples were collected by clipping all aboveground plant parts at 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. All plots were rolled with a custom-designed 4-m wide mechanical roller crimper (Bigham Brothers Inc., Lubbock, TX) prior to glyphosate applied at 1.12 kg ae ha^{-1} as described by Ashford and Reeves (2003) to aid in termination and to provide a uniform mat of residue on the soil surface in high-residue plots. The cotton cultivar 'Phytogen 375 WRF' was planted at both locations in all years. Cotton was planted with a 4-row planter equipped with double-disk openers with row cleaners set to minimize residue disturbance within the row. Plots were four 7.6-m rows spaced 0.97 m apart at EVS and 1.02 m at WGS. Cotton was managed according to Alabama Cooperative Extension recommendations. Cotton at EVS was nonirrigated; at WGS, cotton was irrigated by an overhead irrigation to maintain soil above the permanent wilting point.

Before harvest, plant population and heights were recorded from all cotton plants in randomly selected 3-m sections from the two center rows of each plot. Seed cotton yield was determined by machine harvesting the middle two rows of each plot with a

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Figure 1. A wide residue disturbance (30 cm), 4-row 3-m KMC® Generation 1, 16 Series rip/strip till implement (Kelly Manufacturing Co., Tifton, GA) equipped with two wavy coulters and rolling baskets.

Figure 2. A narrow residue disturbance (<5 cm) 4- row 3-m KMC® Generation 2 subsoiler/leveler implement (Kelly Manufacturing Company) equipped with two pneumatic tires and hard rubber rollers.

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Table 1. Total variable cost by treatment, including fuel and labor used, in economic analysis comparing cover-crop biomass, strip-tillage residue disturbance width, PRE-herbicide placement on cotton weed control, and yield.

Farming operation	Cost (USD) ha^{-1}
Low-residue rye cover crop	135.58
High-residue rye cover crop	261.80
Wide (30 cm) residue disturbance in-row subsoiler	15.39
Narrow (<5cm) residue disturbance in-row subsoiler	15.39
Broadcasted PRE herbicide	48.48
Banded PRE herbicide	10.18

spindle picker. In addition, detailed weed-control ratings by species in early season, prior to the POST and layby applications, where taken in rows and in row middles. In-row and between-row weed control, visually based on biomass reduction as compared with the nontreated control, was estimated in early season on a scale of 0 (native noninjured population) to 100 (complete death of all plants or no plants present) (Frans et al. 1986).

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 minus the costs associated with cover crop establishment, management, and termination; PRE herbicide; and herbicide application costs. To calculate revenue, the price of cotton lint (USD $1.37 kg^{-1}) USDA-NASS 2019) was multiplied by the average percentage lint turnout (0.40) times the cotton yield. All variable input costs were calculated using current prices, and total variable cost for each treatment are presented in Table 1. The price of 'Wrens Abruzzi' cereal rye was obtained from Agri-AFC (Headland, AL). Fertilizer price was obtained from The Feed Lot, Inc. (Pike Road, AL). All other prices were obtained from the 2018 Mississippi State University Cotton Budgets (MSU 2018).

The costs associated with the management of the high-residue rye cover crop included price of cereal rye seed, fertilizer (33-0-0-12S), burndown herbicide (glyphosate; Roundup Powermax®), machinery (i.e., repairs and maintenance for tractors, implements, self-propelled), fuel, and labor. In addition, the high-biomass plots were mechanically rolled flat before planting cotton in the spring. The costs of the two subsoiling treatment operations were assumed to be the same. Both 4-row implements require the same amount of power per shank for in-row tillage and the shank design of each type of subsoiler is identical. The additional energy needed for coulters, rolling baskets, and drag chains on the wide-disturbance subsoiler would likely be negligible compared with the shank power requirements. The broadcasted PRE herbicide costs were calculated as a blanket application (100% coverage in 91-cm rows) with a John Deere® (Moline, IL) 6700 Hiboy sprayer. The banded PRE herbicide costs were calculated using a band sprayer apparatus being attached to the planter; thus, one operation pass is eliminated. A 20-cm band was applied over the row, resulting in only 22% spray coverage, compared with the broadcast treatment. Thus, 78% less herbicide was used in the banded plots as compared with the broadcast plots.

Statistical Analysis

Data were analyzed using generalized linear mixed-model methodology as implemented in PROC GLIMMIX (SAS, version 9.2; SAS Institute, Inc., Cary, NC). Cover-crop biomass, strip-tillage type, herbicide system, and their interactions were considered fixed effects. Effects and interactions were evaluated at P = 0.05. If location was significant at P ≤ 0.05, results were separated and analyzed by location and presented by location. Economic data were analyzed using PROC MIXED, and treatment means were compared using LSD with the same fixed effects. All economic tests were also evaluated at P = 0.05.

Table 2. Cereal rye dry biomass at EVS and WGS, 2011–2013.

	Rye dry biomass[a,b]			
	EVS		WGS	
Year	Low biomass	High biomass	Low biomass	High biomass
	kg ha^{-1}			
2011	102 a	3,119 b	464 b	5,328 a
2012	85 a	3,172 b	250 b	4,787 b
2013	90 a	6,929 a	365 a	4,073 c

[a]Abbreviations: EVS, E.V. Smith Research and Extension Center; WGS, Wiregrass Research and Extension Center.
[b]Least-squares means followed by the same letter are not significantly different; comparisons are within column.

Results and Discussion

Cover Crop

ANOVA revealed significant cover-crop high- versus low-biomass treatment effects on biomass amount for year and location; therefore, biomass results are discussed separately by year and location. At EVS, low-biomass treatments did not differ over years and averaged 92 kg ha^{-1} (Table 2). High-biomass treatments differed, with 6,929 kg ha^{-1} in 2013 compared with an average of 3,146 kg ha^{-1} produced in 2011 and 2012. At WGS, the low-biomass treatments differed, with less biomass produced in 2012 (250 kg ha^{-1}) than in 2011 or 2013, which were similar to each other and averaged 415 kg ha^{-1}. High-biomass treatments differed each year, with 5,328, 4,787, and 4,073 kg ha^{-1} produced in 2011, 2012, and 2013, respectively. Conservation agriculture specialists consider cover-crop biomass amounts exceeding 4,000 kg ha^{-1} as a "high-biomass" system that can increase soil quality (Derpsch et al. 1991). However, for substantial weed suppression, weed scientists recommend greater than 6,000 kg ha^{-1} (Korres and Norsworthy 2015; Price et al. 2016b, 2018; Teasdale and Mohler 2000). Cover-crop biomass in our experiments once met the 6,000 kg ha^{-1} threshold in only 1 site-year; thus, weed control in our experiments was likely less and shorter lasting than that attainable in higher-residue systems. Timely planting of cover crops after cotton is difficult because cotton harvesting is often late, thus reducing biomass (Price et al. 2016b).

Weed Control

ANOVA did not reveal a significant main effect of strip-tillage width on weed control. ANOVA revealed significant PRE application placement and residue amount main effects on weed control for EVS 2013, and WGS 2011 and 2012, with a year-by-location interaction for weeds present at both locations; therefore, weed control results for each site-year are discussed separately. At EVS in 2013, the PRE broadcast application increased row-middle large crabgrass, Palmer amaranth, and tall morning-glory control by 28%, 39%, and 28%, respectively, compared with the PRE banded application (Table 3). In addition, high-residue biomass increased weed control in row middles at least 20% for large

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Table 3. Weed control after either PRE banded or broadcasted herbicide systems, EVS and WGS, 2011–2013.

Site-year: weed	In-row		Row middle	
	PRE (Banded)	PRE (Broadcasted)	PRE (Banded)	PRE (Broadcasted)
	%			
EVS-2013: large crabgrass	83 a	98 a	30 a	81 a
EVS-2013: Palmer amaranth	82 a	99 a	43 a	82 a
EVS-2013: tall morning-glory	89 a	93 a	36 a	64 a
EVS-2013: sicklepod	77 a	84 a	47 a	62 a
WGS-2011: large crabgrass	97 a	97 a	46 b	94 a
WGS-2011: carpetweed	93 b	97 a	41 b	96 a
WGS-2011: yellow nutsedge	66 b	82 a	28 b	68 a
WGS-2011: Palmer amaranth	93 a	95 a	60 b	96 a
WGS-2011: tall morning-glory	66 a	73 a	39 b	77 a
WGS-2011: common purslane	92 a	95 a	30 b	92 a
WGS-2012: large crabgrass	90 a	95 a	75 b	92 a
WGS-2012: carpetweed	96 a	91 a	93 b	99 a
WGS-2012: yellow nutsedge	94 a	93 a	84 a	93 a
WGS-2012: Palmer amaranth	89 a	95 a	92 a	95 a
WGS-2012: tall morning-glory	71 a	85 a	73 a	85 a

[a]Abbreviations: EVS, E.V. Smith Research and Extension Center; WGS, Wiregrass Research and Extension Center.
[b]Least-squares means with the same letter are not significantly different; comparisons are within row between banded and broadcast herbicides for the same weed species within the respective management programs.

Table 4. Weed control in a high- or low-residue cereal rye cover crop system, EVS and WGS, 2011–2013.

Site-Year: Weed	Weed control by residue level[a,b]			
	In-row		Row middle	
	High	Low	High	Low
	%			
EVS-2013: large crabgrass	61 a	60 a	47 a	27 b
EVS-2013: Palmer amaranth	61 a	60 a	56 a	28 b
EVS-2013: tall morning-glory	65 a	57 a	51 a	16 b
EVS-2013: sicklepod	59 a	48 a	56 a	17 b
WGS-2011: large crabgrass	65 a	65 a	58 a	36 b
WGS-2011: carpetweed	65 a	62 b	60 a	31 b
WGS-2011: yellow nutsedge	38 b	61 a	26 a	38 a
WGS-2011: Palmer amaranth	63 a	63 a	65 a	39 b
WGS-2011: tall morning-glory	50 a	43 a	51 a	26 b
WGS-2011: common purslane	62 a	63 a	50 a	31 b
WGS-2012: large crabgrass	62 a	61 a	60 a	52 b
WGS-2012: carpetweed	62 a	62 a	65 a	63 a
WGS-2012: yellow nutsedge	59 b	66 a	60 a	58 a
WGS-2012: Palmer amaranth	60 a	62 a	63 a	61 a
WGS-2012: tall morning-glory	52 a	53 a	52 a	53 a

[a]Abbreviations: EVS, E.V. Smith Research and Extension Center; WGS, Wiregrass Research and Extension Center.
[b]Least-squares means with the same letter are not significantly different; comparisons are within row between high- and low-cover crop residue for the same weed species within the respective management programs.

crabgrass, Palmer amaranth, sicklepod, and tall morning-glory (Table 4). At WGS 2011, carpetweed, common purslane, large crabgrass, Palmer amaranth, tall morning-glory, and yellow nutsedge control in the row middle was 48%, 55%, 40%, 36%, 38%, and 62% greater, respectively, when PRE herbicides were broadcast, compared with the PRE banded treatment (Table 3). For row-middle weed control of yellow nutsedge at WGS, the PRE herbicide activity appeared to be the leading factor in control, because high residues in row middles appeared to decrease *Cyperus* control from almost adequate to very inadequate (Table 4), possibly due to PRE application interception or lack of weed suppression by the cereal rye cover crop (Banks and Robinson 1982; Potter et al. 2008). At WGS 2011, when looking at residue-level effects on row-middle weed control, high-residue biomass resulted in increased carpetweed, common purslane, large crabgrass, Palmer amaranth, and tall morning-glory weed control by at least 19%; however, yellow nutsedge control was again slightly decreased (Table 4). At Wiregrass in 2012, similar weed control trends were observed, compared with 2011 for in-row and row middle for large crabgrass and carpetweed (Table 3). However, greater than 90% control of carpetweed, Palmer amaranth, tall morning-glory, and yellow nutsedge was attained only in PRE broadcast plots (Table 3). Large crabgrass control increased with increased residue at WGS in 2011 and 2012; all other weed control comparisons were not different (Table 4).

PRE banded treatments may provide adequate control in low-weed seedbank situations; however, conservation tillage cotton would likely benefit from broadcast soil-applied herbicide

Table 5. Cover-crop residue, tillage width, and PRE herbicide application effects on cotton population, EVS and WGS, 2011–2013.

	EVS			WGS		
	2011	2012	2013	2011	2012	2013
	Plants ha^{-1}					
Residue level						
High	68,967 b	78,734 a	110,826 a	56,410 b	47,839 b	69,565 a
Low	81,724 a	82,322 a	108,434 a	74,349 a	58,403 a	73,552 a
Tillage width						
Wide	76,343 a	78,136 a	110,029 a	66,177 a	40,065 b	70,961 a
Narrow	74,349 a	82,920 a	109,231 a	64,582 a	66,177 a	72,157 a
PRE herbicide						
Nontreated	72,057 a	75,346 a	110,029 a	68,170 a	52,324 a	68,469 a
Banded	75,944 a	83,717 a	110,029 a	61,592 a	50,230 a	70,263 a
Broadcast	78,037 a	82,522 a	108,833 a	66,376 a	56,808 a	75,944 a

[a]Abbreviations: EVS, E.V. Smith Research and Extension Center; WGS, Wiregrass Research and Extension Center.
[b]Least-squares means with the same letter are not significantly different; comparisons are within each column at each location.

Table 6. Cover crop residue, tillage width, and PRE herbicide application effects on seed cotton yield, EVS and WGS, 2011–2013.

	EVS			WGS		
	2011	2012	2013	2011	2012	2013
	kg ha^{-1}					
Residue level						
High	2,356 b	3,144 a	4,940 a	5,089 b	2,820 a	2,494 a
Low	2,575 a	2,887 b	4,805 a	5,969 a	2,512 a	2,461 a
Tillage width						
Wide	2,397 a	2,922 b	5,035 a	5,495 a	2,483 a	2,422 a
Narrow	2,534 a	3,109 a	4,710 a	5,564 a	2,849 a	2,534 a
PRE herbicide						
Nontreated	2,437 a	2,997 a	4,647 a	5,685 ba	2,525b a	2,308 b
Banded	2,518 a	3,035 a	4,970 a	5,142 b	2,166 b	2,395 ba
Broadcasted	2,441 a	3,015 a	5,000 a	5,761 a	3,307 a	2731 a

[a]Abbreviations: EVS, E.V. Smith Research and Extension Center; WGS, Wiregrass Research and Extension Center.
[b]Least-squares means with the same letter are not significantly different; comparisons are within each column at each location.

applications regardless of residue amount and tillage width when infested with Palmer amaranth and other troublesome weed species. These results agree with the results reported by Hand et al. (2019). Whereas use of only banded herbicides may perform adequately under low or possibly moderate weed infestations, augmentation of the soil weed-seed bank from seed deposited by escapes could adversely affect weed management in future years.

Cotton Population

ANOVA revealed significant cover-crop biomass treatment effects on the cotton population with a year-by-location interaction; therefore, cotton population results are discussed separately by year and location (Table 5). At EVS in 2011, the low-biomass treatment resulted in 81,724 plants ha^{-1}, more than the 68,967 plants ha $^{-1}$ population attained in high-biomass plots. In 2012 and 2013, biomass amount did not influence the cotton population at EVS. At WGS, similar to EVS in 2011, the low-biomass treatment in 2011 and 2012 resulted in 74,349 and 58,403 plants ha^{-1}, respectively. These populations were higher than the populations attained in high-biomass plots in 2011 (56,410 plants ha^{-1}) and 2012 (47,839 plants ha^{-1}), respectively. In 2013, biomass amount did not influence the cotton population at WGS. In a study evaluating row spacing, tillage system, and herbicide technology on cotton populations, the interaction of tillage systems and site-years were attributed to environmental conditions when results differed between years (Balkcom et al. 2010). In addition, plant population variation between conservation systems may be due to such factors as irregular soil disturbance by the subsoiler that the planter cannot operate successfully in, soil–seed contact issues due to "hair pinning" of residue into the subsoiler slot, precipitation events immediately after planting causing downward seed movement into the subsoiler slot, among numerous other factors (Kornecki et al 2009).

Cotton Yield and Economics

ANOVA revealed significant effects of location and year on seed cotton yields, thus results are presented by location and year, and significant effects are discussed. At EVS in 2011, planting into high biomass resulted in cotton yielding 2,356 kg ha^{-1}, whereas low residue resulted in a cotton yield of 2,575 kg ha^{-1} (Table 6). However, results reversed with the higher biomass, resulting in increased yield in 2012. Also at EVS in 2012, planting into a narrow-tillage width resulted in 187 kg ha^{-1} increase in yield. No cotton-yield differences were observed at either location in 2013. Drought occurred at both locations in 2011 and 2012, and yield reflects rainfall deficiency (Figure 3). At WGS, yield was only affected by residue level in 2011 similar to EVS, with low residue resulting in higher yield. Residue amount and tillage width did not affect cotton yields at WGS in 2012 or 2013. Yield was positively influenced by the use of broadcast PRE herbicide at WGS at 2011 and 2012, but not EVS. This result is likely due to the higher population of glyphosate-resistant Palmer amaranth observed at WGS. Thus, non-PRE treatments resulted in less than 80% weed control and lower yield compared with broadcast PRE applications.

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Table 7. Cover crop residue, tillage width, and PRE herbicide application effects on cotton lint revenue, EVS and WGS, 2011–2013.

	Cotton lint revenue[a,b]					
	EVS[c]			WGS		
	2011	2012	2013	2011	2012	2013
	$\$$ ha^{-1}					
Residue level						
High	1,291 b	1,723 a	2,707 a	2,789 b	1,545 a	1,367 a
Low	1,411 a	1,582 b	2,633 a	3,271 a	1,377 a	1,349 a
Tillage width						
Wide	1,313 a	1,601 b	2,759 a	3,011 a	1,361 a	1,327 a
Narrow	1,389 a	1,703 a	2,581 a	3,049 a	1,561 a	1,389 a
PRE herbicide						
Nontreated	1,335 a	1,642 a	2,547 a	3,115 ba	1,384 ba	1,265 b
Bande d	1,380 a	1,663 a	2,724 a	2,818 b	1,187 b	1,312 ba
Broadcasted	1,338 a	1,652 a	2,740 a	3,157 a	1,812 a	1,497 a

[a]U.S. cotton lint price was $1.37 kg^{-1} as of July 2011 (Index Mundi 2020).
[b]Least-squares means with the same letter within a column are not significantly different for each location.
[c]Abbreviations: EVS, E.V. Smith Research and Extension Center; WGS, Wiregrass Research and Extension Center.

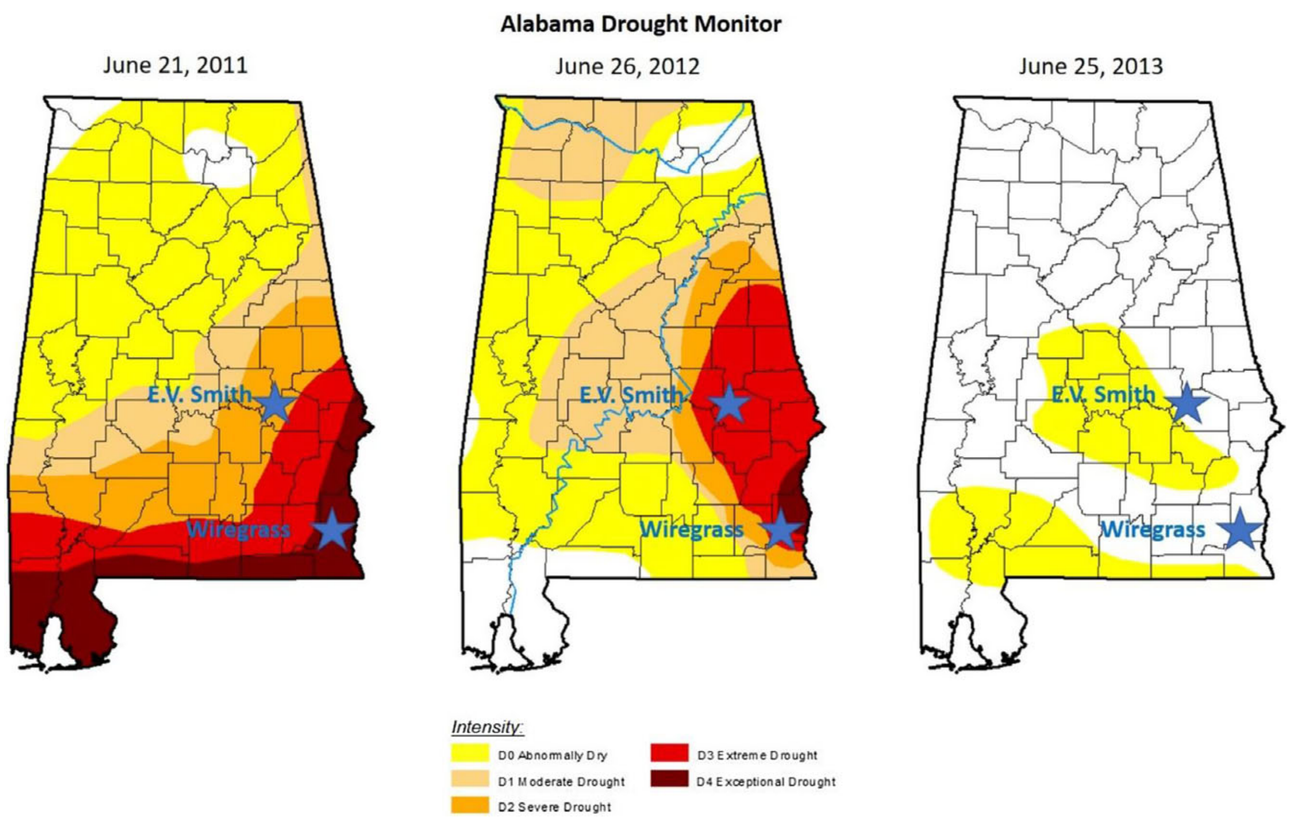

Figure 3. Alabama drought monitor maps generated by the National Oceanic and Atmospheric Administration and University of Nebraska-Lincoln (NOAA-UNL 2020). E.V. Smith, E.V. Smith Research and Extension Center; Wiregrass, Wiregrass Research and Extension Center.

ANOVA revealed significant location-by-year effects on economic returns, thus results are presented by location and year. F tests for yield were also significant for revenue because variable costs among treatments were small compared to yield differences attained under different treatments; thus, revenue differences are the same as yield differences. Revenue ranged from a low of $1,291 ha^{-1} after highresidue at EVS in 2011 to a high of $3,271 ha^{-1} after low residue at WGS in 2011 (Table 7). At EVS in 2012, revenue from the high-residue treatment exceeded that of low residue by $141 ha^{-1}, and revenue from narrow tillage treatment exceeded wide tillage by $102 ha^{-1}, again reflecting yield results. And last, PRE herbicide placement influenced revenue, with higher revenue obtained after broadcast PRE at WGS in 2011 ($339 ha^{-1}) and 2012 ($625 ha^{-1}) compared with revenue after banded applications.

In most comparisons, tillage width, residue amount, and PRE herbicide placement did not influence within-row weed control; however, broadcast PRE resulted in increased large crabgrass, Palmer amaranth, and tall morning-glory weed control in row middles compared with plots receiving banded PRE. In addition,

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high-residue treatment increased large crabgrass, carpetweed, Palmer amaranth, tall morning-glory, sicklepod, and common purslane weed control between rows. Narrow tillage and high levels of cover biomass increased cotton yield and revenue in one of six comparisons, likely due to moisture conservation, whereas banded PRE herbicides resulted in decreased yields and revenue compared with broadcast PRE in two of six comparisons. Our results show that conservation tillage cotton would likely benefit from broadcast soil-applied herbicide applications regardless of residue amount and tillage width when infested with Palmer amaranth and other troublesome weed species. Ball (1992) also hypothesized that conservation tillage systems that leave seed near the soil surface, coupled with effective crop rotation and herbicide regimens, could accelerate depletion of troublesome species from the seedbank. Thus, our efforts to minimize seedbank additions through an integrated approach in conservation tillage systems may help preserve conservation hectarage in the future. Integrated systems that include high-residue cover crops, minimal soil and residue disturbance, and broadcast PRE herbicides that increase weed control to accelerate seedbank depletion are needed to combat troublesome and herbicide-resistant weeds.

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References

Ashford DL, Reeves DW (2003) Use of a mechanical roller-crimper as an alternative kill method for cover crops. American J Alt Agric 18:37–45

Aulakh JS, Price AJ, Balkcom KS (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

Aulakh JS, Price AJ, Enloe SF, van Santen E, Wehtje G, Patterson MG (2012) Palmer amaranth management in glufosinate-resistant cotton: I. Tillage system, cover crops and herbicide management. Weed Management and Herbicide Resistance Special Issue. Agronomy 2:295–311

Aulakh JS, Saini M, Price AJ, Faircloth WH, van Santen E, Wehtje GR, Kelton JA (2015) Herbicide and rye cover crop residue integration affect weed control and yield in strip-tillage peanut. Peanut Sci 42:30–38

Ball DA (1992) Weed seedbank response to tillage, herbicides, and crop rotation sequence. Weed Sci 40:654–659

Banks P, Robinson E (1982) The influence of straw mulch on the soil reception and persistence of metribuzin. Weed Sci 30:164–168

Balkcom KS, Price AJ, van Santen E, Delaney DP, Boykin DL, Arriaga FJ, Bergtold JS, Kornecki TS, Raper RL (2010) Row spacing, tillage system, and herbicide technology affects cotton plant growth and yield. Field Crops Res 117:219–225

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

Cahoon CW, York AC (2019) Weed management in cotton. NCSU Cooperative Extension Publication. https://content.ces.ncsu.edu/cotton-information/weed-management-in-cotton. Accessed: December 2020

Culpepper AS, Grey TL, Vencill WK, Kichler JM, Webster TM, Brown SM, York AC, Davis JW, Hanna WW (2006) Glyphosate-resistant Palmer amaranth (*Amaranthus Palmeri*) confirmed in Georgia. Weed Sci 54:620–626

Culpepper S, Kichler J, Sosnoskie L (2020) University of Georgia programs for controlling moderate to severe populations of glyphosate-resistant Palmer amaranth in cotton. https://athenaeum.libs.uga.edu/handle/10724/12224. Accessed: December 2020

Culpepper AS, York AC, MacRae AW, Kichler J, Whitaker J, Davis AL (2007) Managing glyphosate-resistant Palmer amaranth in conventional and strip-till Roundup Ready cotton. Pages 1230–1231 *in*: Proceedings of the Beltwide Cotton Conference, San Antonio, TX. 4–8 January 2007. Memphis, TN: National Cotton Council of America.

Derpsch R, Roth CH, Sidiras N, Köpke U (1991) Erosion control in Paraná, Brazil: soil cover systems, no-tillage and soil conservation. Eschborn, Germany: Deutsche Gesellschaft für Technische Zusammenarbeit GmbH; SP 245

Frans R, Talbert R, Marx D, Crowley H (1986) Experimental design and techniques for measuring and analyzing plant responses to weed control practices. Pages 37–38 *in*: Camper ND, ed. Research Methods in Weed Science. 3rd ed. Champaign, IL: Southern Weed Science Society

Hand L, Nichols RL, Webster T, Culpepper S (2019). Cereal rye cover crop and herbicide application method impacts cotton stand, Palmer amaranth control, and cotton yield. Weed Technol 33:794–799

Index Mundi (2020) Commodity prices > cotton. https://www.indexmundi.com/commodities/?commodity=cotton. Accessed: September 2020

Kornecki TS, Raper RL, Arriaga FJ, Schwab EB, Bergtold JS (2009) Impact of rye rolling direction and different no-till row-cleaners on cotton emergence and yield. Trans ASABE 52:383–391

Korres NE, Norsworthy JK (2015) Influence of a rye cover crop on the critical period for weed control in cotton. Weed Sci 63:346–352

Loux MM, Dobbels AF, Bradley KW, Johnson WG, Young BG, Spaunhorst DJ, Norsworthy JK, Palhano M, Steckel LE (2017) Influence of cover crops on management of *Amaranthus* species in glyphosate- and glufosinate-resistant soybean. Weed Technol 31:487–495

Mirsky SB, Curran WS, Mortensen DM, Ryan MR, Shumway DL (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 (2018) Cotton 2018 planning budgets. Department of Agricultural Economics, Mississippi State University. Publication 3168. http://extension.msstate.edu/publications/publications/cotton-2018-planning-budgets. Accessed: December 2020

[NOAA-UNL] National Oceanic and Atmospheric Administration, University of Nebraska-Lincoln (2020) U.S. drought monitor. https://droughtmonitor.unl.edu/Maps/MapArchive.aspx. Accessed: September 2020

Norsworthy JK, Griffith GM, Scott RC, Smith KL, Oliver RL (2008) Confirmation and control of glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*) in Arkansas. Weed Technol 22:108–113

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

Palhano MG, Norsworthy JK, Barber T (2017) Cover crops suppression of Palmer amaranth (*Amaranthus palmeri*) in cotton. Weed Technol 32:60–65

Potter TL, Truman CC, Strickland TC, Bosch DD, Webster TM (2008) Herbicide incorporation by irrigation and tillage impact on runoff loss. J Environ Qual 37:839–847

Price AJ, Balkcom KS, Culpepper SA, Kelton JA, Nichols RL, Schomberg H (2011) Glyphosate-resistant Palmer amaranth: a threat to conservation agriculture. J Soil Water Conserv 66:265–275

Price AJ, Korres N, Norsworthy JS, Li S (2018) Influence of a cereal rye cover crop and conservation tillage on the critical weed free period in cotton. Weed Technol 32:683–690

Price AJ, Monks CD, Culpepper AS, Duzy LM, Kelton JA, Marshall MW, Steckel LE, Sosnoskie LM, Nichols RL (2016a) High residue cover crops alone or with strategic tillage to manage glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*) in southeastern cotton (*Gossypium hirsutum*). J Soil Water Cons 71:1–11

Price AJ, Reeves DW, Patterson MG (2006) Evaluation of weed control provided by three winter cereals in conservation-tillage soybean. Renewable Agric Food Sys 21:159–164

Price AJ, Reeves DW, Patterson MG, Gamble BE, Balkcom KS, Arriaga FJ, Monks CD (2007) Weed control in peanut in a high residue conservation-tillage system. Peanut Sci 34:59–64

Price AJ, Saini M, van Santen E, Sarunaite L (2016b) Cover-crop residue amount influences weed suppression, *In*: Abdurakhmonov IY (ed.) Cotton Research. Rijeka, Croatia: IntechOpen. https://www.intechopen.com/books/cotton-research/cover-crop-management-influences-residue-biomass-and-subsequent-weed-suppression-in-a-conservation-a. Accessed: February 8, 20201

Reeves DW, Price AJ, Patterson MG (2005) Evaluation of three winter cereals for weed control in conservation-tillage non-transgenic cotton. Weed Technol 19:731–736

Ryan MR, Curran WS, Grantham AM, Hunsberger LK, Mirsky SB, Mortensen DA, Nord EA, Wilson DO (2011) Effects of seeding rate and poultry litter on weed suppression from a rolled cereal rye cover crop. Weed Sci 59:438–444

Smith AN, Reberg-Horton SC, Place GT, Meijer AD, Arellano C, Mueller JP (2011) Rolled rye mulch for weed suppression in organic no-tillage soybeans. Weed Sci 59:224–231

Smith K, Bond J, Eubank T, Scott RC (2019) Glyphosate-resistant Palmer amaranth and ryegrass management. University of Arkansas Cooperative Extension Fact Sheet MP479. https://www.uaex.edu/publications/PDF/MP479.pdf. Accessed: December 2020

Teasdale JR, Mohler CL (2000) The quantitative relationship between weed emergence and the physical properties of mulches. Weed Sci 48:385–392

[USDA-NASS] U.S. Department of Agriculture, National Agricultural Statistics Service (2019) Quick stats. http://quickstats.nass.usda.gov/. Accessed: December 2020

Van Wychen L (2016) 2016 Survey of the most common and troublesome weeds in broadleaf crops, fruits & vegetables in the United States and Canada. Weed Science Society of America National Weed Survey Dataset. http://wssa.net/wp-content/uploads/2016-Weed-Survey_Broadleaf-crops.xlsx. Accessed: December 2020

Webster TM (2005) Weed survey—southern states: broadleaf crops subsection. Proc South Weed Sci Soc 58:291–304

Webster TM, Cardina J, White AD (2003) Weed seed rain, soil seedbanks, and seedling recruitment in no-tillage crop rotations. Weed Sci 51:569–575

Webster TM, Coble HD (1997) Purple nutsedge (*Cyperus rotundus*) management in corn (*Zea mays*) and cotton (*Gossypium hirsutum*) rotations. Weed Technol 11:543–548

Whitaker JR, York AC, Jordan DL, Culpepper AS (2011) Weed management with glyphosate- and glufosinate-based systems in PHY 485 WRF cotton. Weed Technol 25:183–191

Wise AM, Grey TL, Prostko EP, Vencill WK, Webster TM (2009) Establishing the geographical distribution and level of acetolactate synthase resistance of Palmer amaranth (*Amaranthus palmeri*) accessions in Georgia. Weed Technol 23:214–220