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Influence of Deep Tillage and a Rye Cover Crop on Glyphosate-Resistant Palmer Amaranth (*Amaranthus palmeri*) Emergence in Cotton

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Glyphosate-resistant Palmer amaranth has become a major problem for cotton producers throughout much of the southern United States. With cotton producers relying heavily on glyphosate-resistant cotton, an alternative solution to controlling resistant Palmer amaranth is needed. A field experiment was conducted during 2009 and 2010 at Marianna, AR, in which a rye cover crop and no cover crop were tested in combination with deep tillage with the use of a moldboard plow and no tillage to determine the impact on Palmer amaranth emergence in cotton. To establish a baseline population, 500,000 glyphosate-resistant Palmer amaranth seeds were placed in a 2-m^2 area in the middle of each plot and incorporated into the soil, and emergence was evaluated five times during the season. In 2009, both tillage and the cover crop reduced Palmer amaranth emergence in cotton, but the combination of the two reduced emergence 85%. In the second year, only the cover crop reduced Palmer amaranth emergence in cotton, a 68% reduction. Cover crops and deep tillage will not eliminate glyphosate-resistant Palmer amaranth; however, use of these tools will likely reduce the risks of failures associated with residual herbicides along with selection pressure placed on both PRE- and POST-applied herbicides. Additional efforts should focus on the integration of the best cultural practices identified in this research with use of residual herbicides and greater focus on limiting Palmer amaranth seed production and reducing the soil seedbank.

Nomenclature: Glyphosate; Palmer amaranth, *Amaranthus palmeri* S. Wats.; cotton, *Gossypium hirsutum* L. 'Stoneville 4554 B2RF'; rye, *Secale cereale* L. 'Wrens Abruzzi'.
Key words: Cover crop, cultural weed control, mechanical weed control, moldboard plow, pigweed, weed suppression.

El *Amaranthus palmeri* resistente a glyphosate se ha convertido en un gran problema para los productores de algodón a lo largo del sur de los Estados Unidos. Al depender los productores de algodón, fuertemente de algodón resistente a glyphosate, se necesita una solución alternativa para controlar *A. palmeri* resistente. Se realizó un experimento de campo durante 2009 y 2010 en Marianna, AR, en el cual se evaluó el centeno como cultivo de cobertura y la ausencia de cultivo de cobertura en combinación con labranza profunda con el uso de arado de vertedera y cero labranza, para determinar el impacto en la emergencia de *A. palmeri* en el algodón. Para establecer una población base se pusieron 500 000 semillas de *A. palmeri* resistente a glyphosate en un área de 2 m^{-2} en el centro de cada parcela y se incorporaron al suelo, y la emergencia fue evaluada cinco veces durante la temporada de crecimiento. En 2009, ambos sistemas de labranza y el cultivo de cobertura redujeron la emergencia de *A. palmeri* en algodón, pero la combinación de ambos redujo la emergencia en 85%. En el segundo año, solamente el cultivo de cobertura redujo la emergencia de *A. palmeri* en el algodón, con una reducción de 68%. Los cultivos de cobertura y la labranza profunda no eliminarán *A. palmeri* resistente a glyphosate. Sin embargo, el uso de estas herramientas probablemente reducirá el riesgo asociado a fallas en el control con herbicidas residuales, además de la presión de selección asociada a herbicidas PRE y POST. Esfuerzos adicionales deberían enfocarse en la integración de las mejores prácticas culturales identificadas en esta investigación con el uso de herbicidas residuales y un mayor énfasis en limitar la producción de semilla de *A. palmeri* y así reducir el banco de semillas.

The inherent lack of competitiveness early in the growing season consequently makes cotton a labor-intensive crop requiring many inputs from the producer (Buchanan and Burns 1970). Weed control can be one of the most expensive components in a cotton-production system, especially when a producer is dealing with a problem weed such as glyphosate-resistant Palmer amaranth. Palmer amaranth is a member of the genus *Amaranthus*, which comprises approximately 60 species native to the Americas (Sauer 1967). Glyphosate-resistant Palmer amaranth infests more than 310,000 ha in Arkansas alone (Nichols et al. 2009) and was ranked the second most problematic weed by Arkansas cotton consultants in a 2006 survey (Norsworthy 2007). More recently, Palmer amaranth has been deemed the most troublesome weed of cotton in Arkansas, Mississippi, and Tennessee, mainly because of its prevalence throughout the cotton-production regions of these states along with its resistance to glyphosate and acetolactate synthase–inhibiting herbicides (Norsworthy et al. 2012a).

Palmer amaranth is troublesome because of its rapid growth rate, it can reach heights of up to 2 m or more (Garvey 1999; Norsworthy et al. 2008), exorbitant seed production (Keeley et al. 1987), season-long emergence (Jha et al. 2006), and resistance to herbicides (Heap 2011). A mature female Palmer amaranth is capable of producing 600,000 or more seeds per plant (Keeley et al. 1987). Controlling Palmer amaranth early is crucial to prevent the rapid spread of this weed. If not controlled, Palmer amaranth can spread more than 100 m across a field in the first year (Griffith et al. 2009).

Palmer amaranth is highly competitive with crops; numerous experiments have been designed to determine the effects of pigweeds in cotton (Buchanan et al. 1980; Crowley

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and Buchanan 1978; Morgan et al. 2001; Rowland et al. 1999; Rushing et al. 1985a, 1985b; Smith et al. 2000; Street et al. 1985). Cotton lint yield decreased linearly 13 to 57% in response to increasing Palmer amaranth densities from 1 to 10 plants every 9.1 m of row (Morgan et al. 2001). A similar linear relationship was reported by Rowland et al. (1999), but with even greater yield losses (12 to 92%) at one to eight Palmer amaranth plants 10 m^{-1} of row.

Not only does Palmer amaranth lower cotton yields, it also reduces harvesting efficiency. Actual harvest time increased from 79 min ha^{-1} in weed-free plots to 91 min ha^{-1} in plots with a Palmer amaranth density of 3,260 plants ha^{-1}, and an additional 183 min ha^{-1} were required to clear blockages in the harvester (Smith et al. 2000). Along with the increase in harvesting time, the greatest Palmer amaranth density caused a 2.4% loss of harvestable yield because of harvester inefficiencies. Loss of profits caused by low cotton yields and increased harvest costs are primary examples of why producers across the southern United States need an effective method to control Palmer amaranth.

The introduction of glyphosate-resistant cotton in 1997 dramatically changed cotton production. In 1996, glyphosate was used on only 13% of U.S. cotton hectares (National Agricultural Statistics Service, United States Department of Agriculture [NASS] 1997), mostly as a preplant burndown treatment. However, by 2003, glyphosate was being used on 70% of U.S. cotton hectares, and was the most commonly used herbicide in cotton (NASS 2001, 2004). By 2007, 91% of U.S. cotton was glyphosate resistant (Dill et al. 2008). The rapid, widespread adoption of the glyphosate-resistant technology and overreliance on glyphosate inevitably led to the evolution of glyphosate-resistant Palmer amaranth. As a result of increased selection pressure from glyphosate, the weed species most common in cotton fields today are either glyphosate tolerant or glyphosate resistant. Because of this shift from susceptible to glyphosate-resistant weed biotypes, alternative control measures, including cultural and mechanical means of control, must be evaluated and integrated into weed management programs to mitigate further resistance evolution to glyphosate and other herbicides.

Cover crops are a cultural management tactic that can reduce soil erosion and compaction, increase soil moisture under the mulch of the cover crop, and provide weed suppression through physical suppression, competition for resources, or through chemical allelopathic effects (Clark et al. 1994; Creamer et al. 1996; Galloway and Weston 1996; Putnam and DeFrank 1983; Teasdale and Daughtry 1993). In cotton, the two most commonly recommended cover crops are cereal rye and soft red winter wheat (*Triticum aestivum* L.) (McCarty et al. 2003; Monks and Patterson 1996). Legume cover crops such as hairy vetch (*Vicia villosa* Roth) have been shown to be unsuitable in providing a high level of weed suppression in cotton because of rapid decay of the cover crop following its termination (Norsworthy et al. 2010). When compared with several other cover crops, rye provided superior early-season control of Palmer amaranth in cotton, with as much as 91% control without the use of herbicides, and complete control with various herbicide programs (Norsworthy et al. 2011).

Rye did not affect cotton emergence when compared to cotton grown alone, and lint yield was greater in cotton with rye as a cover crop than cotton following fallow or legume cover crops (Bauer and Busscher 1996) or wheat (Reeves et al. 2005). Rye has also been reported to have greater weed suppression than wheat (Phatak 1998). The use of a rye cover crop alone provided as much as 92% control of Palmer amaranth and redroot pigweed (*Amaranthus retroflexus* L.) in Alabama cotton because of the high amount of residue created by the rye (Price et al. 2008).

A mechanical form of weed control that may aid management of Palmer amaranth is deep tillage with a moldboard plow. Deep tillage was once used as the primary form of weed control in many crops; however, as environmental issues such as soil erosion and pesticide runoff began to cause greater concern, more emphasis was placed on conservation-tillage and no-tillage practices in an effort to make agricultural production practices more sustainable. Until the evolution of glyphosate-resistant weeds such as Palmer amaranth, glyphosate-resistant cotton allowed increased cotton production in conservation-tillage systems because of the broad-spectrum POST control possible with glyphosate (Norsworthy et al. 2011). However, with the adoption of conservation-tillage practices that reduce or eliminate tillage as a weed control technique, reliance on herbicides as the primary form of weed control has increased. Although deep tillage is not a common practice today in midsouth cotton production (Norsworthy et al. 2012a), it is an effective means of burying *Amaranthus* seed deep enough to reduce emergence (Leon and Owen 2006). Because of the potential that successive, annual deep tillage events will return buried seed to the soil surface, a one-time or infrequent deep tilling of the soil would be most effective at burying weed seed as well as minimizing soil erosion issues, especially when used in conjunction with a weed-suppressive cover crop.

Glyphosate-resistant Palmer amaranth has created a problem for which there are few herbicide control options in cotton. In addition to glyphosate, many biotypes are resistant to ALS-inhibiting herbicides. Thus, using a rye cover crop and deep tillage with a moldboard plow to reduce the competitiveness and emergence of Palmer amaranth should improve the effectiveness of current herbicide programs in cotton and help to lower glyphosate-resistant Palmer amaranth seed production and the soil seedbank. Therefore, the objectives of this research were to evaluate the effect of a rye cover crop and deep tillage with the use of a moldboard plow on Palmer amaranth emergence and plant density in cotton over a 2-yr period, determine if soil properties are affected by either practice, and determine the cost of each practice and combination of practices.

Materials and Methods

A field experiment was conducted at the Lon Mann Cotton Research Station at Marianna, AR, in 2009 and 2010 on a Convent silt loam (coarse–silty, mixed, superactive, nonacid, thermic Fluvaquentic Endoaquepts) (Anonymous 2012b). The experiment was conducted in a randomized complete block design with a two by two factorial arrangement of

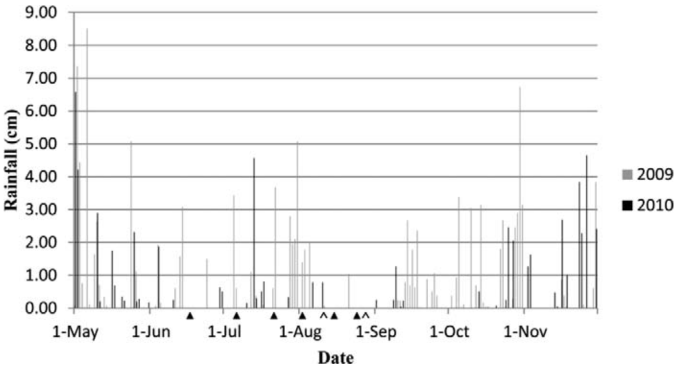

Figure 1. Rainfall and irrigation distribution in 2009 and 2010 at Marianna, AR. Irrigation events in 2009 shown by a ^. Irrigation events in 2010 shown by a ▲.

treatments replicated four times. Factors were deep tillage with a moldboard plow or no deep tillage, and the presence or absence of a rye cover crop. Plots were 7.7 m (eight rows) wide by 60 m long, and treatments occupied the same plots in 2009 and 2010. A 2-m^2 area was marked in the center of each plot by a global positioning system at initiation of the experiment in the fall of 2008 and then used for introduction of glyphosate-resistant Palmer amaranth into the plots as described below.

In early November 2008, approximately 500,000 viable glyphosate-resistant Palmer amaranth seed were placed in the 2-m^2 area. The number of Palmer amaranth seed was determined by counting 1,000 seed, weighing them, and then using that weight to determine the weight of 500,000 seed. After seed were weighed and placed in the field, all the plots were disked twice in opposite directions with the use of a disk harrow for uniform seed incorporation to an approximate depth of 10 cm. In November of 2008, assigned plots were deep tilled with the use of a moldboard plow to a depth of 30 cm. Plots that received deep tillage were smoothed with two passes of a field cultivator. All plots were then bedded with the use of an eight-row hipper and roller.

On November 17, 2008, and November 20, 2009, 'Wrens Abruzzi' rye was drill-seeded at 67 kg ha^{-1} with the use of a no-till grain drill. After rye was planted, test plots were broadcast fertilized with 34 kg ha^{-1} K and 67 kg ha^{-1} P. In the spring of 2009 and 2010, the rye cover crop was desiccated with glyphosate (Roundup PowerMax®, Monsanto Company, St. Louis, MO 63167) at 870 g ae ha^{-1} 2 wk prior to planting. At the time of desiccation in 2009, the rye was 83 cm tall with a biomass of 672 g m^{-2}. In 2010, rye was 77 cm tall with a biomass of 590 g m^{-2} at the time of desiccation. On May 19, 2009 and May 20, 2010, 'Stoneville 4554 B2RF' cotton seed was planted at 136,000 seed ha^{-1} directly into standing rye and plots with no rye with the use of a four-row planter equipped with double-disk openers. Cotton was side-dressed with 34 kg ha^{-1} N twice during the growing season. The test site was furrow irrigated twice in 2009 and six times in 2010 (Figure 1). During both growing seasons, Palmer amaranth plants were counted and removed every 3 to 4 wk for a total of five times per growing season to determine the number of seedlings that emerged within each plot. The area counted was the width of the plot by 6 m from the center in both directions for a total area of 92 m^2. The experimental site had a natural population of susceptible Palmer amaranth, but no glyphosate-resistant Palmer amaranth prior to initiating the experiment based on prior observation. Because of this, the experimental site was oversprayed with glyphosate at 870 g ae ha^{-1} 1 wk before each counting date. Therefore, the glyphosate-resistant Palmer amaranth seeded in each plot in 2008 was counted.

An attempt was made to determine the impact of deep tillage and a rye cover crop on the Palmer amaranth soil seedbank by counting seeds in soil cores collected from the 0- to 15- and 15- to 30-cm depths in the fall of 2008, 2009, and 2010. Four techniques were used: emergence from the soil cores placed in flats in the greenhouse; emergence from soil cores mixed with a commercial potting soil, extracting seeds with the use of an elutriator normally used to extract nematodes from soil samples, and hand-sieving the soil to separate it from the seed. Because none of these methods was successful for determining the Palmer amaranth seed content in the soil samples, the samples were abandoned.

Soil samples were collected from the 0- to 15-cm depth, and soil bulk density, organic matter, soil pH, and sand, silt, and clay content were determined. A single sample was collected from the top of one bed in each plot. All samples were oven dried for 2 wk at 70 C and weighed to determine bulk density. The dried samples were ground and sieved in a 2-mm sieve, and a 50-g subsample was mixed with 50 ml of sodium hexametaphosphate solution (100 g L^{-1}) and placed in a 1-L sedimentation cylinder, which was then filled with distilled water to the 1-L mark. Hydrometer readings were recorded at 40 s and 2 h with the use of the Bouyoucos scale in grams per liter and then used to determine the percent sand, silt, and clay of each sample. These percentages were then used to determine the soil texture of each sample according to the soil textural triangle.

Cotton density and seed-cotton yield were determined both seasons. Palmer amaranth emergence data were square-root transformed and normality was confirmed with the use of the Shapiro-Wilk test (Shapiro and Wilk 1965). All data were then subjected to ANOVA with the use of PROC MIXED in SAS (v 9.1, SAS Institute, Inc., Cary, NC) with year, tillage, and cover crop as fixed effects. Means were separated based on the least significant difference (LSD) assigned with the use of the PDMIX 800 procedure in SAS. The cost of deep tillage, a rye cover crop, and the combinations of these tactics was determined with the use of the Mississippi State Budget Generator v 6.0 (Anonymous 2012a). This program, developed by the Department of Agricultural Economics at Mississippi State University, allows users to develop enterprise and whole farm budgets and estimate income and expenses to aid in decision making. Budgeting procedures consist of user-defined inputs that include the price of fuel, labor, and equipment, which can be adjusted to fit the user's needs.

Results and Discussion

Soil Characteristics. Deep tillage and cover crop did not influence soil properties in the top 15 cm compared to plots with no deep tillage or cover crop. Soil pH and organic matter

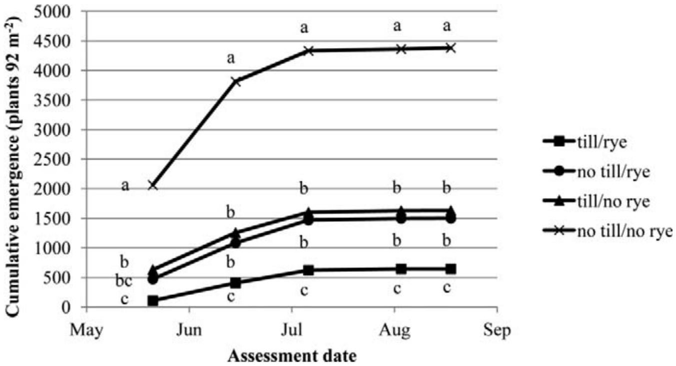

Figure 2. Cumulative Palmer amaranth emergence in 2009 as a function of deep tillage and a rye cover crop. Means with the same letter within each assessment date are not significantly different according to Fisher's LSD ($\alpha = 0.05$). Abbreviations: till, deep tillage; no till, no deep tillage; rye, rye cover crop; no rye, no rye cover crop.

Table 1. ANOVA for factors influencing cumulative Palmer amaranth emergence by assessment date.

	Significance of factors and interactions		
Assessment date	Tillage	Cover crop	Tillage by cover crop
		P value	
Year 1 (2009)			
May 21	0.0004	0.0001	0.1208
June 15	< 0.0001	< 0.0001	0.0020
July 7	< 0.0001	< 0.0001	0.0148
Aug 4	< 0.0001	< 0.0001	0.0215
Aug 19	< 0.0001	< 0.0001	0.0209
Year 2 (2010)			
May 19	0.9764	0.1580	0.9248
June 8	0.8173	0.0014	0.6074
June28	0.6784	0.0017	0.6752
July 20	0.4098	0.0021	0.7150
Aug 17	0.3641	0.0023	0.7719
Total emergence	0.0068	< 0.0001	0.1314

were similar for all treatments, with a mean pH of 6.2 and organic matter concentration of 1.5% (data not shown). Soil particle-size distribution showed an average of 19% sand, 74% silt, and 7% clay with no differences among treatments (data not shown). Soil bulk density also did not differ among treatments and averaged 1.2 g cm^{-3} (data not shown). With no treatment effects on near-surface soil properties, neither cotton nor Palmer amaranth growth would have been differentially affected among treatment combinations.

Palmer Amaranth Emergence. Years are presented separately because of a significant year by treatment interaction.

Year 1. Palmer amaranth cumulative emergence was greatest in plots without deep tillage and a rye cover crop throughout the growing season (Figure 2). Both the deep tillage alone and the rye cover crop alone provided significantly better control than the no deep-tillage/no cover-crop treatment. Deep tillage alone reduced Palmer amaranth emergence 69% early in the growing season, compared to no deep tillage or cover crop, and resulted in a cumulative emergence reduction of 63% over the entire growing season. This was similar to the reduction in emergence that was provided by a rye cover crop alone. The rye cover crop reduced Palmer amaranth emergence by 77% early in the growing season and only 66% reduction of cumulative emergence over the entire growing season compared to no deep tillage or cover crop. Similar to the results of this study, a rye cover crop reduced Palmer amaranth and redroot pigweed emergence by 76% during a 2-yr study in Alabama (Price et al. 2008). The greatest reduction in emergence resulted from the combination of deep tillage and a rye cover crop. Combining the two strategies reduced Palmer amaranth emergence by 95% early in the growing season, and emergence reduction was still 85% by the end of the growing season.

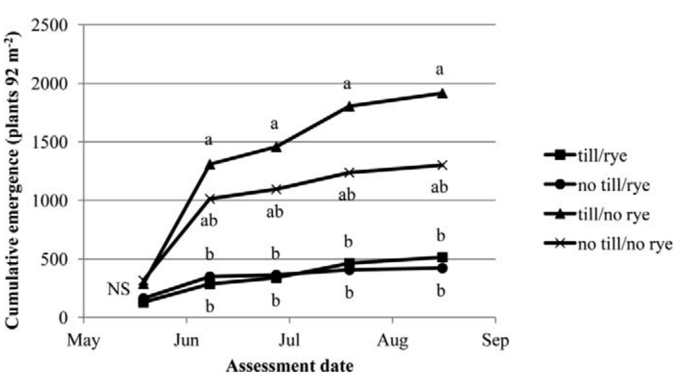

Figure 3. Cumulative Palmer amaranth emergence in 2010 as a function of deep tillage and a rye cover crop. Means with the same letter within each assessment date are not significantly different according to Fisher's LSD ($\alpha = 0.05$). Abbreviations: till, deep tillage; no till, no deep tillage; rye, rye cover crop; no rye, no rye cover crop.

Year 2. Prior to planting in 2010, plots that did not have a rye cover crop had to be rebedded because of bed erosion over the winter months. Beds were still intact in plots that had a rye cover crop, so rebedding was not necessary. Rebedding impacted Palmer amaranth emergence in that Palmer amaranth seed buried by the moldboard plow in the fall of 2008 were likely brought back to the soil surface when the plots were rebedded based on the observed increase in emergence. When plots with no deep tillage and no cover crop were rebedded, no additional seed were brought to the soil surface because no seed were initially deeply buried. Plots with deep tillage and no cover crop had 47% more Palmer amaranth emergence than plots with no deep-tillage or cover crop (Figure 3). When a cover crop alone or a cover crop with deep tillage was used, Palmer amaranth emergence was reduced 60 to 68% over the entire growing season (Figure 3).

Total Emergence. Rebedding plots with no cover crop resulted in no significant interaction between deep tillage and the cover crop over the 2-yr period (Table 1). Averaged over tillage, the rye cover crop reduced Palmer amaranth emergence by 67% compared to no cover crop over the 2-yr period (data not shown). When averaged over cover crop, the use of deep tillage in 2009 lowered Palmer amaranth emergence by 38% compared to no deep tillage. These results would most likely have been different had the plots not needed to be re-bedded in 2010. As seen in 2009 (year 1), deep tillage alone can reduce Palmer amaranth emergence

Table 2. Influence of deep tillage and cover crop on total Palmer amaranth emergence, cotton stand count for 2009 and 2010, and seed-cotton yield for 2009 and 2010.[a]

Deep tillage	Cover crop	Total Palmer amaranth emergence[b]	Cotton stand count 2009	Cotton stand count 2010	Seed-cotton yield 2009	Seed-cotton yield 2010
		No. 92 m^{-2}	No. m^{-1} row		kg ha^{-1}	
None	None	5,684 a	10.0 a	11.8 a	2,852 a	2,146 a
Tilled	None	3,546 b	9.8 a	10.5 a	2,517 a	2,297 a
None	Rye	1,922 c	11.5 a	11.5 a	2,,802 a	2,352 a
Tilled	Rye	1,160 c	10.0 a	10.3 a	2384 a	2,336 a

[a] Means within a column followed by the same letter are not different according to Fisher's LSD test ($\alpha = 0.05$).

[b] Total Palmer amaranth emergence for 2009 and 2010.

nearly 70% (Figure 2). In other research, deep tillage with the use of a moldboard plow reduced common waterhemp [*Amaranthus tuberculatus* (Moq.) Sauer] emergence by at least 73% and as much as 98% with no crop present (Leon and Owen 2006). Furthermore, a rye cover crop used in combination with PRE-applied herbicides can provide similar weed control to that of a high-input herbicide system (Reeves et al. 2005), further justifying integrating these practices into existing cotton production systems.

An average of 0.6% of the total Palmer amaranth seeds that were placed in each plot emerged over the 2-yr study, which was similar to the 0.5 to 0.8% Palmer amaranth emergence observed during a 4-yr study in South Carolina (Jha and Norsworthy unpublished data). Jha and Norsworthy (unpublished data) also reported that if Palmer amaranth seeds were left undisturbed in the soil seedbank for at least 2 yr, less than 0.1% of the seed would remain viable. Therefore, if deep tillage were used in combination with a rye cover crop to prevent the need for rebedding for two or more years, the viable population of Palmer amaranth seeds in the soil seedbank could be substantially diminished; however, this does not mean that Palmer amaranth will be eliminated from the soil seedbank. Hence, continued efforts to control Palmer amaranth are necessary to prevent seed entry into the soil seedbank. In this study, because all emerged Palmer amaranth were hand removed, no additional Palmer amaranth seed entered the soil seedbank. In production fields, seed production prevention will likely be achieved by integrating some combination of cultural practices outlined in this research with effective herbicide programs, particularly those containing residual herbicides (Norsworthy et al. 2012b).

Cotton Density and Yield. Cover crop and deep tillage did not affect cotton density either year compared to no cover crop or deep tillage (Table 2). In 2009 (year 1) and 2010 (year 2), cover crop and deep tillage did not influence seed-cotton yields compared to plots with no cover crop or deep tillage (Table 2). Although tillage and rye did not affect cotton density or yield, Palmer amaranth density was impacted by these practices, which would probably lead to increased yields when deep tillage and a rye cover crop are used in fields containing glyphosate-resistant Palmer amaranth. Seed-cotton yields averaged slightly more than 2,600 kg ha^{-1} in 2009 and slightly less than 2,300 kg ha^{-1} in 2010. Norsworthy et al. (2011) also reported comparable yields between cotton grown with and without a rye cover crop in AR. Similarly in the southeast, Reeves et al. (2005) reported no difference in yield of cotton grown with or without a rye cover crop.

Cost of Practices. Producers seldom practice weed management strategies that are designed to prevent the evolution of herbicide-resistant weeds because the cost of preventing herbicide-resistant weeds is thought to be the same as managing herbicide-resistant weeds (Beckie 2006). With the short-term cost increase viewed as uneconomical, producers often only change their weed management practices when resistance has evolved (Beckie 2006).

The cost of each treatment combination was determined with the use of the Mississippi State Budget Generator. Moldboard plowing alone cost \$75.03 ha^{-1}, which included the cost of machinery, fuel, and labor for plowing and two passes with a field cultivator to level the soil surface after moldboard plowing (Table 3). When the rye cover crop was used alone, the incurred expense was \$377.38 ha^{-1}, which included the cost of rye seed, planting the rye cover crop with the use of a no-till grain drill, an application of 34 kg ha^{-1} K and 67 kg ha^{-1} P, an application of glyphosate at 870 g ae ha^{-1} to desiccate the rye prior to planting, and the cost of machinery, fuel, and labor for each process (Table 3). When seeding a rye cover crop in combination with moldboard plowing, a conventional grain drill can be used in place of a no-till grain drill, reducing the cost of seeding the rye cover crop by \$33.81 ha^{-1} compared to using a no-till drill, making the total cost of deep tillage plus a rye cover crop \$418.60 ha^{-1} (Table 3).

Table 3. Breakdown of total additional cost for each treatment compared to no deep tillage and no rye cover crop.

Inputs	Costs for treatments: Till/no rye	No till/rye	Till/rye
	\$ ha^{-1}		
MB plow[a]	51.43	–	51.43
Field cultivator	23.60	–	23.60
Conventional grain drill	–	–	25.75
No-till grain drill	–	59.56	–
Rye	–	71.11	71.11
Potash	–	63.70	63.70
Phosphate	–	172.54	172.54
Glyphosate application	–	10.47	10.47
Total	75.03	377.38	418.60

[a] Abbreviations: MB, moldboard plow; Till, deep tillage.

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The greatest reduction in Palmer amaranth emergence resulted from the combination of deep tillage and a rye cover crop; however, the additional cost of a rye cover crop was much greater than deep tillage alone. To understand the economic benefit of rye fully, an experiment that allows for interference of Palmer amaranth plants in rye with cotton is needed, whereas in this study, Palmer amaranth seedlings were removed throughout the growing season. Models that account for seed production and capture the long-term economics would be needed to determine fully if the combination of deep tillage and a rye crop in a program that includes effective herbicides would be profitable and beneficial to the long-term sustainability of herbicides (i.e., lower the risk of resistance). Based on this research, it is unlikely that a producer can avoid rebedding if not using a cover crop, which will negate some of the benefit of deep tillage for reducing Palmer amaranth emergence. Because of the extra cost, the combination of these practices might be better suited for fields having small areas of glyphosate-resistant Palmer amaranth, prior to a major outbreak of this resistant weed. Using this strategy prior to a major outbreak of resistance would greatly reduce cost by allowing the producer to treat only the infested area to prevent Palmer amaranth from spreading further across the field and should aid resistance management by reducing the number of Palmer amaranth seedlings, particularly those resistant to glyphosate, that would likely be controlled with the use of other residual and POST-applied herbicides.

Acknowledgments

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