Weed Technology 2013 27:612–622

Education/Extension

Assessment of Weed Management Practices and Problem Weeds in the Midsouth United States—Soybean: A Consultant's Perspective

Dilpreet S. Riar, Jason K. Norsworthy, Lawrence E. Steckel, Daniel O. Stephenson, IV, Thomas W. Eubank, and Robert C. Scott*

Soybean consultants from Arkansas, Louisiana, Mississippi, and Tennessee were surveyed by direct mail and by on-farm visits in fall 2011 to assess weed management practices and the prevalence of weed species in midsouth U.S. soybean. These consultants represented 15, 21, 5, and 10% of total soybean planted in Arkansas, Louisiana, Mississippi, and Tennessee, respectively, in 2011. Collectively, 93% of the total scouted area in these four states was planted with glyphosate-resistant (RR) soybean. The adoption of glufosinate-resistant (LL) soybean was greatest in Arkansas (12%), followed by Tennessee (4%), Mississippi (2%), and Louisiana (< 1%). Only 17% of the RR soybean was treated solely with glyphosate, compared with 35% of LL soybean treated solely with glufosinate. Across four states, average cost of herbicides in RR and LL soybean systems was US$78 and US$91 ha^{-1}, respectively. Collectively across states, total scouted area under conventional tillage was 42%, stale seedbed was 37%, and no-tillage was 21%. Palmer amaranth and morningglories were the most problematic weeds in all four states. Additionally, barnyardgrass and horseweed were the third most problematic weeds of Arkansas and Tennessee, respectively, and Italian ryegrass was the third most problematic weed in Louisiana and Mississippi. Glyphosate-resistant Palmer amaranth infested fewer fields in Louisiana (16% of fields) than it did in the remaining three states (54% collectively). Average Palmer amaranth hand-weeding costs in the midsouth was US$59 ha^{-1}. Three-fourths of the midsouth consultants stipulated the need for continued research and education focused on management of glyphosate-resistant and glyphosate-tolerant weed species.

Nomenclature: Glufosinate; glyphosate; barnyardgrass, *Echinochloa crus-galli* (L.) Beauv.; horseweed, *Conyza canadensis* (L.) Cronq.; Italian ryegrass, *Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot; morningglory, *Ipomoea* spp.; Palmer amaranth, *Amaranthus palmeri* S. Wats.; soybean, *Glycine max* (L). Merr.

Key words: Glufosinate-resistant soybean, glyphosate-resistant soybean, resistance management, tillage, weed control, weed management survey, weed species shift.

Asesores en soya de Arkansas, Louisiana, Mississippi, y Tennessee fueron encuestados vía correo y visitas en finca en el otoño de 2011 para evaluar las prácticas de manejo de malezas y la prevalencia de especies de malezas en la producción de soya en el Sur medio de los Estados Unidos. Estos asesores representaron 15, 21, 5 y 10% del total de soya plantada en Arkansas, Louisiana, Mississippi, y Tennessee, respectivamente en 2011. Colectivamente, 93% del total del área evaluada en estos cuatro estados fue sembrada con soya resistente a glyphsoate (RR). La adopción de soya resistente a glufosinate (LL) fue mayor en Arkansas (12%), seguida por Tennessee (4%), Mississippi (2%) y Louisiana (<1%). Solamente 17% de la soya RR fue tratada únicamente con glyphosate, al compararse con 35% de soya LL que fue tratada solamente con glufosinate. En los cuatro estados, el costo promedio de herbicidas en sistemas de soya RR y LL fue US$78 y US$91 ha^{-1}, respectivamente. Colectivamente en los estados, el total del área evaluada que estuvo bajo labranza convencional fue 42%, siembra retrasada 37%, y cero labranza 21%. *Amaranthus palmeri* e *Ipomoea* spp. fueron las malezas más problemáticas en todos los cuatro estados. Adicionalmente, *Echinochloa crus-galli* y *Conyza canadensis* fueron las terceras malezas más problemáticas en Arkansas y Tennessee, respectivamente, y *Lolium perenne* fue la tercera maleza más problemática en Louisiana y Mississippi. *A. palmeri* resistente a glyphosate infestó menos campos en Louisiana (16% de los campos) que en el resto de los tres estados (54% colectivamente). El promedio del costo de deshierba manual de *A. palmeri* en el Sur medio fue de US$59 ha^{-1}. Tres cuartos de los asesores del Sur medio estipularon la necesidad de investigación y educación continuas enfocadas en el manejo de malezas resistentes y tolerantes a glyphosate

DOI: 10.1614/WT-D-12-00167.1

* Postdoctoral Associate and Professor, Department of Crop, Soil, and Environmental Sciences, 1366 West Altheimer Drive, Fayetteville, AR 72704; Associate Professor, Department of Plant Sciences, University of Tennessee, 605 Airways Boulevard, Jackson, TN 38301; Associate Professor, Dean Lee Research Station, Louisiana State University AgCenter, 8105 Tom Bowman Drive, Alexandria, LA 71302; Assistant Extension/Research Professor, Delta Research and Extension Center, 82 Stoneville Road, Stoneville, MS 38776; Professor, Department of Crop, Soil, and Environmental Sciences, Box 357, Lonoke, AR 72086. Corresponding author's E-mail: driar@uark.edu

The rapid adoption of glyphosate-resistant (Roundup Ready [RR], Monsanto) soybean is attributed to the simplicity and flexibility of the technology, allowing growers to increase income by using the time saved in weed-management operations in off-farm activities (Fernandez-Cornejo and Caswell 2006). Ease to practice conservation tillage, greater rotational crop flexibility, and minimal herbicide toxicity further increased the adoption of herbicide-resistant soybean systems (Bradley 2000).

Ninety-three percent of the current soybean acreage in the United States is planted with herbicide-resistant soybean

(USDA-NASS 2012). The RR soybean system represents most of the acreage seeded to herbicide-resistant soybean and is followed by small proportions of conventional, glufosinate-resistant (Liberty Link [LL], Bayer CropScience), and sulfonylurea-tolerant soybean (STS) systems. As is apparent from a 20-fold increase in the use of glyphosate from 1994 to 2006 (Benbrook 2009), wide adoption of RR soybean has resulted in the substitution of commonly used herbicides, such as imazaquin, imazethapyr, metribuzin, pendimethalin, and trifluralin, with glyphosate. Glyphosate is often applied at a higher rate and frequency, compared with the herbicides it replaced, resulting in an overall increase in herbicide use in RR soybean. compared with conventional soybean systems (NRC 2010). According to recent surveys, herbicide-resistant soybean systems, of which, RR soybean predominates, on average, used 4% more herbicides during 1998, 16% more herbicide from 1999 through 2002, and 30% more herbicide from 2003 through 2009, compared with conventional soybean in the U.S. (Bonny 2011).

Increased glyphosate use was logical because of the adoption of RR soybean; however, from 2002 to 2006, there was 2.6-fold increase in the overall use of preplant 2,4-D in the United States, which can be attributed to the evolution of glyphosate resistance in common weeds, such as glyphosate-resistant horseweed (Benbrook 2009). Increased reliance on RR crops in the past 15 yr led to the number of glyphosate-resistant weed species increasing from 1 in 1996 to 24 in 2012 (Heap 2012). In the United States, 14 species and 90 biotypes of glyphosate-resistant weeds have been reported, with a likely increase in that number if proper resistance-management strategies are not soon implemented.

Not only did the continuous reliance on glyphosate in RR soybean result in the evolution of glyphosate-resistant weeds, but its extensive use additionally caused a shift toward glyphosate-tolerant weeds or those that escape control as a result of late emergence (Reddy and Norsworthy 2010). Weed species, such as hemp sesbania [*Sesbania herbacea* (P. Mill.) McVaugh], morningglories, prickly sida (*Sida spinosa* L.), yellow nutsedge (*Cyperus esculentus* L.), and some others, have inherent tolerance to glyphosate (Scott et al. 2013; Shaner 2000). Annual grasses and pigweed (*Amaranthus* spp.) emerge in several flushes throughout the season and often escape early season glyphosate applications because of the absence of residual herbicides (Tharp and Kells 2002).

The glyphosate-based systems that were once a solution to most weed management problems are going through a metamorphosis because of the prevailing glyphosate-resistant and glyphosate-tolerant weed species (Webster and Sosnoskie 2010). Glyphosate-resistant Palmer amaranth, by itself, has profoundly impaired soybean production in the midsouth United States, leading to major changes in weed management strategies (Green and Owen 2011; Norsworthy et al. 2012; Osunsami 2009). A benchmark survey of 22 U.S. corn (*Zea mays* L.) and soybean states and the cotton (*Gossypium hirsutum* L.) region in 2010 to assess the grower attitude and awareness regarding glyphosate-resistant weeds showed that growers in the South were more aware and concerned about glyphosate-resistant weeds (Prince et al. 2012b).

Because of the continuous efforts of weed scientists and extension specialists to educate growers about best management practices to mitigate herbicide-resistant weeds, many southern soybean growers have reverted back to the agricultural practices used in the 1980s and earlier, by bringing back the use of multiple residual herbicides, cultivation, and hand-weeding (Hammond 2010). Recently, a special issue of the journal *Weed Science* published two manuscripts that focused solely on understanding resistance evolution, especially under herbicide-resistant cropping systems (Vencill et al. 2012), and best management practices and recommendations to reduce the risk of herbicide resistance (Norsworthy et al. 2012). Further knowledge about current crop production practices, troublesome weeds, weed management programs, and the extent of resistance management practices being adopted will help weed scientists develop more-efficient weed management programs for midsouth soybean growers.

Soybean consultants routinely scout fields and recommend needed crop production and weed management practices to growers and, therefore, have first-hand information about the common constraints to soybean production and management of troublesome weeds (Norsworthy et al. 2007). A weed management survey was constructed for soybean consultants in the midsouth United States to determine the current geographic area under specific herbicide-resistant traits and the soybean production practices, troublesome weed species, cost of current weed management programs, and extent of the area infested with glyphosate-resistant Palmer amaranth.

Materials and Methods

Registered crop consultant's names and addresses were obtained from the Agricultural Consultants Associations of Arkansas, Louisiana, Mississippi, and Tennessee in fall 2011. A survey questionnaire was directly mailed to all of the registered crop consultants from Arkansas ($n = 255$) and Mississippi ($n = 66$) and were hand-delivered to randomly selected soybean consultants from Louisiana ($n = 61$) and Tennessee ($n = 54$). The survey in Arkansas and Mississippi was sent to all consultants because soybean consultants were not specified in the list provided by the Agricultural Consultants Associations of these states. The survey questionnaire was divided into four sections: (1) desired weed management research to improve soybean production, (2) general weed management, (3) herbicide-resistance management, and (4) glyphosate-resistant Palmer amaranth.

The first section of the survey asked consultants to suggest two areas of research that would help improve weed management in soybean. General weed management questions for the second section are listed in Table 1. In addition, in that section, consultants were provided with the list of 40 potential problem weeds and were asked to rate the importance of each on a scale of 1 to 5, with 1 = not important, 2 = rarely important, 3 = occasionally important, 4 = important, and 5 = very important. They were also asked to list their three most problematic weeds, with number 1 = most problematic, number 2 = second most problematic, and number 3 = third most problematic weed. In the third

https://doi.org/10.1614/WT-D-12-00167.1 Published online by Cambridge University Press

Table 1. Questionnaire on general weed management in glyphosate-resistant and glufosinate-resistant soybean.[a,b]

	Section 2: General weed management
1	Total soybean acres you scouted this year ______
2	What percent of your scouted acres were planted to glyphosate-resistant (Roundup Ready) soybean?
3	What percent of your scouted glyphosate-resistant soybean acres were rotated at least once during the last three years with a non-glyphosate-resistant crop?
4	Did any of your growers plant continuous glyphosate-resistant soybean in the same field over the last 5 years? ______ Yes _______ No
5	What percent of your acres were planted to continuous glyphosate-resistant soybean over the last 5 years?
6	What percent of your scouted acres were treated with glyphosate excluding burndown?
7	What percent of your scouted acres were treated *solely* (no additional herbicides) with glyphosate?
8	What percent of your scouted acres was treated with a preemergence herbicide followed by glyphosate?
9	What percent of your scouted acres were planted to glufosinate-resistant (Liberty Link) soybean?
10	What percent of your scouted acres were treated *solely* with glufosinate (Ignite)?
11	What percent of your scouted acres were treated with a preemergence herbicide followed by Ignite?
12	How much on an average did your growers spend on herbicides in a glyphosate-based system in 2011?
13	How much on an average did your growers spend on herbicides in a glufosinate (Ignite)-based system in 2011?
14	What percent of your scouted acres are described by the below tillage practices? ______ Conventional tillage ______ Stale seedbed ______ No-tillage ______ Row cultivation ______ Deep tillage

[a] Data in acres were converted to hectares.

[b] Ignite has been recently renamed as Liberty to align with LibertyLink technology.

section, consultants were asked whether herbicide-resistant weeds were present in the soybean fields they scout. They were provided with a list of resistance management practices and were asked to rate the importance of each on a scale of 1 to 5, similar to the rating of potential weed problems. Additionally, they were asked to describe the obstacles to adoption of each of the listed resistance-management practices. The third section of the survey is not covered here but will be summarized in an article aimed at understanding the adoption of herbicide management strategies in cotton, rice, and soybean and limitations to the adoption of those practices (J. K. Norsworthy, unpublished data). Questions related to spread and control of glyphosate-resistant Palmer amaranth were included in the fourth section and are listed in Table 2.

State and collective problematic ranking for each weed species was calculated by assigning 3 points, 2 points, and 1 point to the first, second, and third most-problematic weed, respectively (Norsworthy et al. 2007; Webster and MacDonald 2001). Each species that was not ranked among the three most-problematic weeds by a consultant was assigned a value of 0. In addition, state and collective importance ranking of all listed weed species were calculated based on the point values assigned by consultants.

Results and Discussion

Soybean Area Scouted. A total of 57, 21, 12, and 10 registered consultants returned the surveys ($n = 100$) from Arkansas, Louisiana, Mississippi, and Tennessee, respectively, in fall 2011. These consultants represented 15% (199,162 ha), 21% (84,783 ha), 5% (39,741 ha), and 10% (49,858 ha) of total soybean planted in Arkansas (1,347,633 ha), Louisiana (412,788 ha), Mississippi (736,544 ha), and Tennessee (522,056 ha), respectively, in 2011 (USDA-NASS 2012).

General Weed Management Practices. In 2011, area planted with herbicide-resistant (all traits) soybean was 95% in Arkansas, 92% in Louisiana, 98% in Mississippi, and 92% in Tennessee of the total area under soybean in those states (USDA-NASS 2012). Because of monetary and nonmonetary benefits, RR soybean technology has been widely embraced by U.S. growers (Hurley et al. 2009). Out of the total area scouted by consultants, 88%, > 99%, 98%, and 96% in Arkansas, Louisiana, Mississippi, and Tennessee, respectively, was under RR soybean cultivars. The collective area under RR cultivars in these four midsouthern states was 93%. Of the remaining scouted area, the LL soybean system was used in

https://doi.org/10.1614/WT-D-12-00167.1 Published online by Cambridge University Press

Table 2. Questionnaire on the spread and management of glyphosate-resistant Palmer amaranth.[a]

	Section 4: Glyphosate-resistant Palmer amaranth
1	Rate your concern with glyphosate-resistant Palmer amaranth (Circle most appropriate) a) None b) Slight c) Moderate d) High
2	Do you suspect glyphosate-resistant Palmer amaranth on the farms you scout? ______ Yes ______ No
3	On what percent of your scouted acres have you observed glyphosate-resistant Palmer amaranth? ______
4	Has tillage increased on your farms as a result of glyphosate-resistant Palmer amaranth? ______ Yes ______ No
5	What percent of your acres was cultivated specifically to control Palmer amaranth? ______
6	Do you have growers that are hand removing (chopping) Palmer amaranth? ______ Yes ______ No
7	What percent of your acres was hand-weeded for Palmer amaranth? ______
8	Of the growers removing Palmer amaranth by hand, what was the average cost of removal? ______ $/acre
9	How many times were fields (% of scouted acres) hand-weeded for Palmer amaranth? Place a percent in each blank. ______ None ______ Twice ______ ≥Four times ______ Once ______ Thrice
10	What criteria, if any, are being used to decide when Palmer amaranth will be hand-removed from fields? (Circle all that are used) a) size of weed b) hoe crew availability c) after last herbicide application d) any time prior to harvest e) prior to weed seed production
11	There are several new herbicide resistance traits that may be registered over the next five years in soybean for improved Palmer amaranth control (and other weeds). What, if any, grower obstacles will limit adoption of these future technologies? dicamba (Clarity) resistance ______________________________ HPPD (Callisto, Balance Flexx, etc.) resistance ______________________________

[a] Data in acres were converted to hectares.

Arkansas (12%), Louisiana (< 1%), Mississippi (2%), and Tennessee (4%). In 2009, the soybean hectares infested with glyphosate-resistant Palmer amaranth were 88,000 in Arkansas, 11,000 in Mississippi, and 14,000 ha in Tennessee (Nichols et al. 2009). Widespread infestation of glyphosate-resistant Palmer amaranth in soybean is the probable reason for the greater adoption of LL soybean in Arkansas compared with other midsouth states.

Growers are reluctant to shift from RR soybean technology to nonglyphosate-resistant alternatives because they perceive these alternatives as more costly and less time efficient (Green and Owen 2011). Based on our survey, consultants reported that only 53, 25, 45, and 4% of the scouted soybean hectares in Arkansas, Louisiana, Mississippi, and Tennessee, respectively, were rotated at least once with another nonglyphosate-resistant crop in the past 3 yr. Collectively, in these four states, 75% of consultants confirmed continuous RR soybean plantation without any crop or herbicide-resistant trait rotation by their growers during the past 5 yr. Out of the total scouted area under RR soybean in these states, 44% of the area was under continuous RR soybean in the past 5 yr. The average producer was under an RR soybean system for 9 yr in the 2010 benchmark survey of 22 U.S. corn and soybean states (Prince et al. 2012b).

Weeds with delayed emergence or emergence in multiple flushes escape control with nonresidual herbicides, such as glyphosate and glufosinate (Neve et al. 2003; Reddy and Norsworthy 2010). The survey results suggest that glyphosate, excluding preplant burndown applications, was used on 91% of the total scouted area in Arkansas, Louisiana, Mississippi, and Tennessee. Seventeen percent of the total scouted RR soybean area in these four states was treated solely with glyphosate (Table 3). Similarly, 35% of the total scouted LL soybean area was treated solely with glufosinate. The benchmark survey of 2010 also confirmed that more growers in 2010, compared with 2005, have integrated additional herbicides other than glyphosate in continuous RR soybean systems (Prince et al. 2012a). Although sole use of glyphosate in RR soybean has decreased recently because of the evolution of glyphosate-resistant Palmer amaranth, the use of glufosi-

Table 3. Percentage of the area under different herbicide programs in the midsouth (data pooled for Arkansas, Louisiana, Mississippi, and Tennessee).

Herbicide program[a]	Area % of scouted soybean[b]
Solely glyphosate	17
PRE fb glyphosate	61
Solely glufosinate	35
PRE fb glufosinate	65

[a] Abbreviation: fb, followed by.

[b] Area under glyphosate-containing and glufosinate-containing programs is presented as the percentage of glyphosate-resistant and glufosinate-resistant soybean, respectively.

https://doi.org/10.1614/WT-D-12-00167.1 Published online by Cambridge University Press

Table 4. Consultant's perspective on the average area under different tillage practices (standard error in parenthesis) by state and collectively in the midsouth United States.

Tillage practice	Arkansas	Louisiana	Mississippi	Tennessee	Midsouth
	% of total scouted area				
Conventional tillage	53 (4.1)	28 (6.1)	32 (9.5)	20 (6.8)	42 (3.2)
Stale seedbed	32 (3.8)	61 (6.1)	45 (9.3)	7.0 (4.8)	37 (3.2)
No tillage	15 (2.5)	11 (3.0)	23 (8.8)	73 (9.3)	21 (2.7)
Row cultivation	5.5 (2.2)	7.1 (4.8)	15 (8.6)	1.0 (1.0)	6 (1.9)
Deep tillage	2.9 (1.6)	1.7 (1.1)	0.9 (0.9)	1.0 (1.0)	2 (0.9)

nate alone in LL soybean is alarmingly high in these midsouth states.

Area treated with a PRE-applied herbicide, followed by glyphosate in RR soybean and glufosinate in LL soybean was 61 and 65%, respectively, of the total area planted under those two systems in four states collectively (Table 3). Residual herbicides are crucial for obtaining season-long control of glyphosate-resistant Palmer amaranth (Jha and Norsworthy 2009; Neve et al. 2011). Improved early season control of glyphosate-resistant and glyphosate-susceptible weed species with PPI residual herbicides in RR and LL soybean and cotton has been widely reported (Culpepper et al. 2000; Riar et al. 2011a). The average cost of herbicides in RR soybean was US\$78 ha^{-1} and in LL soybean was US\$91 ha^{-1} in the midsouth collectively. The lower cost of glyphosate relative to glufosinate is likely the reason for the lower herbicide cost in RR soybean compared with LL soybean.

Collectively, the total scouted area of the four midsouth states was under conventional tillage, stale seedbed, no-tillage, row cultivation, and deep tillage in 42, 37, 21, 6, and 2%, respectively (Table 4). Area under conventional tillage was highest in Arkansas (53%), whereas nearly three-fourths of the scouted area in Tennessee was under no-tillage soybean. In addition to weed management, topography partly contributes to the choice of tillage practices in these states. Although, adoption of no-tillage and reduced tillage practices increased dramatically throughout the United States after deregulation of RR soybean (Cerdeira and Duke 2006), adoption was greatest in Tennessee because of the rolling topography of western Tennessee that aids surface drainage and soil erosion, highly erodible silt-loam soils, and high-intensity rainstorms during spring and summer months (Mueller et al. 2005). No-tillage productions systems in western Tennessee reduced soil erosion by up to 90% (USDA-NRCS 2000). A survey of soybean tillage practices conducted by the U.S. Department of Agriculture, Economic Research Service in 2006 reported no-tillage on 15% of total planted soybean in Arkansas, 26% in Louisiana, 35% in Mississippi, and 74% in Tennessee (Horowitz et al. 2010).

Historically, adoption of RR soybean and use of glyphosate for broad-spectrum weed control favored no-tillage practices, but at the cost of the evolution of glyphosate-resistant weeds, such as Palmer amaranth. Several tillage practices assist in countering soil seedbank accumulation of herbicide-resistant weeds in midsouth soybean production systems. For example, interrow cultivation can alleviate selection pressure for evolution of herbicide resistance, and deep tillage can bury the small seed of Palmer amaranth and other weed species deep enough (up to 30 cm) to prevent successful germination and emergence (DeVore et al. 2013; Norsworthy et al. 2011, 2012). Area under stale seedbed was 32, 61, and 45% in Arkansas, Louisiana, and Mississippi, respectively, but was only 7% in Tennessee (Table 4). Row cultivation and deep tillage are traditionally a part of conventional tillage; however, growers have once again begun incorporating row cultivation and deep tillage as resistance management tools in the midsouth soybean production systems (Table 4). The intensity of conventional tillage is likely to increase to control herbicide-resistant weeds and to limit the number of weeds present at crop harvest because those weeds often contribute to the soil seedbank.

Problem Weeds. Palmer amaranth, morningglory, barnyardgrass, and horseweed were first, second, third, and fourth most-problematic weeds in soybean in the four states collectively (Table 5). Topography, environmental variations, soil moisture, and agronomic practices, such as tillage and crop rotation, influence the efficacy of weed management tactics, thereby augmenting or diminishing the prevalence of specific weed species at specific locations (Ball 1992; Cardina et al. 2002).

To demonstrate the association of problematic weeds to specific states, the top-five most-problematic weeds are listed by state (Table 5). Palmer amaranth and morningglories were the first and second most-problematic weeds in Arkansas, Mississippi, and Tennessee, whereas morningglory ranked above Palmer amaranth in Louisiana. Italian ryegrass was the third most-problematic weed of soybean in Louisiana and Mississippi; however, horseweed was third and fourth most-problematic weed of Tennessee and Arkansas, respectively. Barnyardgrass was among the top five problematic weeds in Arkansas, Louisiana, and Tennessee. Similar to the problem ranking, Palmer amaranth, morningglories, barnyardgrass, and horseweed were among the top five most important weeds of soybean in the midsouth (Table 5). Although johnsongrass [*Sorghum halepense* (L.) Pers.] was not ranked among the top five problematic weeds, it was ranked second overall based on importance in the midsouth, which might be due to its widespread occurrence along roads and field borders in the midsouth region (M. V. Bagavathiannan, unpublished data) and the recent evolution of glyphosate-resistant johnsongrass biotype in Arkansas, Mississippi, and Louisiana (Heap 2012; Riar et al. 2011b).

Weed shifts toward glyphosate-resistant and glyphosate-tolerant weed species in a glyphosate-based management system has been widely documented (Kruger et al. 2009; Norsworthy 2008; Norsworthy et al. 2012). Evolution and spread of glyphosate-resistant Palmer amaranth (Norsworthy

Table 5. Consultant's ranking of weeds in soybean in the midsouth United States (data from Arkansas, Louisiana, Mississippi, and Tennessee combined), along with the top-five most-problematic weeds of those states.

Common name	Scientific name	Problematic points (SEM)[a]	Problematic rank	Importance points (SEM)[b]	Importance rank
Palmer amaranth	*Amaranthus palmeri* S. Wats.	2.29 (0.12)	1	4.58 (0.09)	1
Morningglory	*Ipomoea* spp.	0.86 (0.10)	2	4.17 (0.09)	3
Barnyardgrass	*Echinochloa crus-galli* (L.) Beauv.	0.38 (0.08)	3	3.91 (0.12)	4
Horseweed	*Conyza canadensis* (L.) Cronq.	0.35 (0.07)	4	3.74 (0.13)	5
Prickly sida	*Sida spinosa* L.	0.19 (0.06)	5	3.03 (0.12)	13
Annual grasses[c]	—	0.19 (0.06)	5	—	—
Hemp sesbania	*Sesbania herbacea* (P. Mill.) McVaugh	0.17 (0.05)	6	3.28 (0.12)	9
Italian ryegrass	*Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot	0.14 (0.06)	7	3.12 (0.14)	10
Yellow nutsedge	*Cyperus esculentus* L.	0.14 (0.05)	7	3.51 (0.10)	6
Sicklepod	*Senna obtusifolia* (L.) H.S. Irwin & Barneby	0.12 (0.04)	8	2.84 (0.12)	14
Giant ragweed	*Ambrosia trifida* L.	0.09 (0.05)	9	2.52 (0.12)	19
Johnsongrass	*Sorghum halepense* (L.) Pers.	0.09 (0.04)	9	4.22 (0.09)	2
Broadleaf signalgrass	*Urochloa platyphylla* (Nash) R.D. Webster	0.08 (0.05)	10	3.37 (0.12)	7
Red rice	*Oryza sativa* L.	0.07 (0.03)	11	2.78 (0.17)	15
Common waterhemp	*Amaranthus rudis* Sauer	0.07 (0.04)	11	2.66 (0.14)	17
Crabgrass	*Digitaria* spp.	0.06 (0.04)	12	3.11 (0.12)	11
Henbit	*Lamium amplexicaule* L.	0.06 (0.04)	12	3.30 (0.14)	8
Groundcherry	*Physalis* spp.	0.06 (0.04)	12	2.38 (0.12)	25
Browntop millet	*Brachiaria ramosa* (L.) Stapf	0.06 (0.04)	12	1.86 (0.11)	39
Spreading dayflower	*Commelina diffusa* Burm. f.	0.04 (0.03)	13	1.97 (0.11)	35
Texas gourd[d]	*Cucurbita pepo* L. var. *texana* (Scheele) D. Decker	0.04 (0.03)	13	—	—
Northern jointvetch	*Aeschynomene virginica* (L.) B.S.P.	0.03 (0.02)	14	2.41 (0.13)	23
Smartweeds	*Polygonum* spp.	0.03 (0.02)	14	3.09 (0.12)	12
Redvine	*Brunnichia ovata* (Walt.) Shinners	0.03 (0.02)	14	2.49 (0.11)	21
Itchgrass[d]	*Rottboellia cochinchinensis* (Lour.) W.D. Clayton	0.03 (0.03)	14	—	—
Fall panicum	*Panicum dichotomiflorum* Michx.	0.01 (0.01)	15	2.51 (0.12)	20
Hophornbeam copperleaf	*Acalypha ostryifolia* Riddell	0.01 (0.01)	15	2.16 (0.10)	29
Goosegrass	*Eleusine indica* (L.) Gaertn.	0.01 (0.01)	15	2.48 (0.12)	22
Cutleaf evening-primrose	*Oenothera laciniata* Hill	0.01 (0.01)	15	2.49 (0.12)	21
Spotted spurge	*Chamaesyce maculata* (L.) Small	0.01 (0.01)	15	1.98 (0.10)	34
Common ragweed	*Ambrosia artemisiifolia* L.	0.01 (0.01)	15	2.20 (0.10)	27
Bermudagrass	*Cynodon dactylon* (L.) Pers.	0.01 (0.01)	15	2.40 (0.11)	24
Common lambsquarters	*Chenopodium album* L.	0	0	1.88 (0.09)	38
Eclipta	*Eclipta prostrata* (L.) L.	0	0	2.06 (0.11)	31
Common cocklebur	*Xanthium strumarium* L.	0	0	1.99 (0.10)	33
Curly dock	*Rumex crispus* L.	0	0	2.18 (0.10)	28
Chickweed	*Cerastium* spp. and *Stellaria* spp.	0	0	2.00 (0.10)	32
Carolina geranium	*Geranium carolinianum* L.	0	0	2.27 (0.11)	26
Common purslane	*Portulaca oleracea* L.	0	0	2.15 (0.10)	30
Shepherd's-purse	*Capsella bursa-pastoris* (L.) Medik.	0	0	1.92 (0.09)	37
Spurred anoda	*Anoda cristata* (L.) Schlecht.	0	0	1.96 (0.09)	36
Velvetleaf	*Abutilon theophrasti* Medik.	0	0	2.56 (0.11)	18
Annual bluegrass	*Poa annua* L.	0	0	2.67 (0.13)	16
Top five problematic weeds of Arkansas[e]					
Palmer amaranth	*Amaranthus palmeri* S. Wats.	2.60 (0.13)	1	4.75 (0.10)	1
Morningglory	*Ipomoea* spp.	0.65 (0.11)	2	4.11 (0.13)	3
Barnyardgrass	*Echinochloa crus-galli* (L.) Beauv.	0.47 (0.12)	3	4.14 (0.15)	2
Horseweed	*Conyza canadensis* (L.)	0.37 (0.09)	4	3.91 (0.15)	5
Hemp sesbania	*Sesbania herbacea* (P. Mill.) McVaugh	0.18 (0.07)	5	3.58 (0.14)	6
Sicklepod	*Senna obtusifolia* (L.) H.S. Irwin & Barneby	0.18 (0.07)	5	2.87 (0.16)	15
Prickly sida	*Sida spinosa* L.	0.18 (0.06)	5	2.93 (0.16)	13
Top-five problematic weeds of Louisiana					
Morningglory	*Ipomoea* spp.	1.24 (0.25)	1	4.25 (0.19)	2
Palmer amaranth	*Amaranthus palmeri* S. Wats.	0.95 (0.29)	2	3.80 (0.26)	5
Italian ryegrass	*Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot	0.43 (0.21)	3	3.80 (0.21)	5
Barnyardgrass	*Echinochloa crus-galli* (L.) Beauv.	0.38 (0.19)	4	3.70 (0.25)	6
Johnsongrass	*Sorghum halepense* (L.) Pers.	0.33 (0.19)	5	4.45 (0.15)	1
Common waterhemp	*Amaranthus rudis* Sauer	0.33 (0.19)	5	2.90 (0.32)	10
Itchgrass	*Rottboellia cochinchinensis* (Lour.) W.D. Clayton	0.33 (0.14)	5	—	—
Top-five problematic weeds of Mississippi[e,f]					
Palmer amaranth	*Amaranthus palmeri* S. Wats.	2.55 (0.25)	1	4.75 (0.13)	1
Morningglory	*Ipomoea* spp.	1.09 (0.37)	2	4.33 (0.26)	2
Italian ryegrass	*Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot	0.45 (0.25)	3	4.17 (0.37)	3
Hemp sesbania	*Sesbania herbacea* (P. Mill.) McVaugh	0.36 (0.20)	4	3.25 (0.33)	11
Annual grasses	—	0.36 (0.24)	4	—	—

Table 5. Continued.

Common name	Scientific name	Problematic points (SEM)[a]	Problematic rank	Importance points (SEM)[b]	Importance rank
Broadleaf signalgrass	*Urochloa platyphylla* (Nash) R.D. Webster	0.27 (0.27)	5	3.50 (0.42)	8
Prickly sida	*Sida spinosa* L.	0.27 (0.19)	5	3.58 (0.31)	7
Top five problematic weeds of Tennessee					
Palmer amaranth	*Amaranthus palmeri* S. Wats.	2.90 (0.11)	1	5.00 (0.0)	1
Morningglory	*Ipomoea* spp.	1.00 (0.31)	2	4.20 (0.21)	4
Horseweed	*Conyza canadensis* (L.) Cronq.	0.90 (0.40)	3	4.60 (0.23)	2
Sicklepod	*Senna obtusifolia* (L.) H.S. Irwin & Barneby	0.20 (0.14)	4	3.20 (0.41)	8
Giant ragweed	*Ambrosia trifida* L.	0.20 (0.21)	4	3.40 (0.36)	6
Annual grasses	—	0.20 (0.14)	4	—	—
Barnyardgrass	*Echinochloa crus-galli* (L.) Beauv.	0.10 (0.11)	5	2.90 (0.33)	10
Johnsongrass	*Sorghum halepense* (L.) Pers.	0.10 (0.11)	5	4.40 (0.23)	3

[a] Problematic points were calculated by assigning 3, 2, and 1 points to the first, second, and third most-problematic weeds, respectively, from each survey. Each species that was not ranked among three most-problematic weeds by a consultant was assigned a value of 0. Standard errors of the mean for each weed species is provided in parentheses.

[b] Importance points were calculated based on the point value assigned to each weed by consultants. The rating scale was 1 = not important, 2 = rarely important, 3 = occasionally important, 4 = important, and 5 = very important. Standard errors of the mean for each weed species is provided in parentheses.

[c] Species not specified by the consultants.

[d] Texas gourd and itchgrass were not included in the list of important weeds in soybean in the survey but were problematic weeds according to some consultants.

[e] Johnsongrass was ranked as second and fourth most important weed in Mississippi and Arkansas, respectively.

[f] Horseweed was fifth most important weed in Mississippi.

et al. 2008; Steckel et al. 2008), giant ragweed (*Ambrosia trifida* L.) (Norsworthy et al. 2011), horseweed (Koger et al. 2004), and Italian ryegrass (Nandula et al. 2012) biotypes and inherent tolerance of morninglory, hemp sesbania, and prickly sida (Jordan et al. 1997; Riar et al. 2011a) to glyphosate is most likely the reason for the dominance of these weed species in glyphosate-based soybean systems in the midsouth. Norsworthy and Oliver (2002) predicted an increase in the difficulty of controlling morningglory in RR soybean because of its ability to produce seeds after a single or sequential applications of glyphosate.

Resistance or tolerance to glyphosate, however, is not the reason for ranking barnyardgrass among the top-five problematic and important weeds in Arkansas and Louisiana (Table 5). Barnyardgrass is susceptible to glyphosate and glufosinate applications (Scott et al. 2013) but emerges over an extended period throughout the cropping season (Bagavathiannan et al. 2011). Prolonged emergence, along with the prevalence of safe sites, aids the escape of barnyardgrass plants from glyphosate and glufosinate, resulting in late-season seed production and replenishment of the soil seedbank. Additionally, soybean in Arkansas, Mississippi, and Louisiana is often rotated with rice (*Oryza sativa* L.), with barnyardgrass having evolved resistance to many herbicides applied for its control in rice, including propanil (Baltazar and Smith 1994), quinclorac (Lovelace 2003), clomazone (Norsworthy et al. 2009), and several acetolactate synthase-inhibiting herbicides (Riar et al. 2012, 2013). A prolonged emergence period, coupled with reduced barnyardgrass control in rice, has increased prevalence of barnyardgrass in the soybean fields rotated with rice in the midsouth.

Glyphosate-Resistant Palmer Amaranth Management. Because Palmer amaranth was ranked sixth in Louisiana, compared with first in Arkansas, Mississippi, and Tennessee (Table 5), the data for glyphosate-resistant Palmer amaranth management are discussed separately for Louisiana but are pooled for Arkansas, Mississippi, and Tennessee (referred to as the *remaining midsouth*). Sixty-two percent of consultants in Louisiana and 99% in the remaining midsouth suspected glyphosate-resistant Palmer amaranth in their scouted fields. Consultants reported that the percentage of total scouted area infested with glyphosate-resistant Palmer amaranth was 16% in Louisiana, compared with 54% in the remaining midsouth. The first case of glyphosate-resistant Palmer amaranth in Louisiana was reported in 2010, compared with 2006 in Arkansas and Tennessee and 2008 in Mississippi (Heap 2012). Delayed evolution of resistance in Louisiana justifies less area under glyphosate-resistant Palmer amaranth compared with the remaining midsouth. Evolution of glyphosate-resistant weed species (Palmer amaranth and johnsongrass) in Louisiana was delayed until 2010 because of cropping systems and weed management programs that included soil-applied residual herbicides during planting and a combination of glyphosate with other herbicides (Griffin and Webster 2012; Heap 2012).

When asked to rate concern (none, slight, moderate, and high) regarding glyphosate-resistant Palmer amaranth, only 71% of consultants from Louisiana, compared with 90% from the remaining midsouth, showed a high level of concern. When compared with the survey of Nichols et al. (2009), our survey shows that presence of glyphosate-resistant Palmer amaranth in midsouth soybean has increased immensely during the past few years.

Soil disturbance is an important resistance-management tool, and hence, tillage intensity has recently increased in the midsouth (Horowitz et al. 2010). In Louisiana, only 3.5% of consultants reported an increase in tillage because of glyphosate-resistant Palmer amaranth, another reflection that resistance is less of an issue in Louisiana. In contrast, 72% of

Table 6. Area under different frequencies of Palmer amaranth hand-weeding in Louisiana and remaining midsouth (data pooled for Arkansas, Mississippi, and Tennessee).

Hand-weeding frequency	Louisiana	Remaining midsouth
	% of total scouted area	
None	96.5	83
Once	2.0	13
Twice	1.0	1.5
Three times	0.5	0.5
> four times	0	0

consultants from the remaining midsouth acknowledged increased tillage with respect to glyphosate-resistant Palmer amaranth. Two percent of the total scouted area in Louisiana and 31% in the remaining midsouth were cultivated to control glyphosate-resistant Palmer amaranth.

Currently, because of the evolution of multiple resistances to glyphosate and acetolactate synthase (ALS)-inhibiting herbicides in Palmer amaranth, midsouth soybean growers have few effective, over-the-top herbicide options. These options would include several protoporphyrinogen oxidase (PPO)-inhibiting herbicides, 2,4-DB, and glufosinate in LL soybean (Scott et al. 2013); however, those options must be applied before Palmer amaranth reaches 10 cm, which is quite challenging in the absence of residual weed control. Hence, midsouth growers are returning to hand-weeding under a "zero tolerance to Palmer amaranth seed production" policy initiated by extension specialists and weed scientists (Norsworthy et al. 2012). Validating this claim, 35 and 79% of consultants from Louisiana and the remaining midsouth, respectively, confirmed that growers are hand-weeding fields to remove Palmer amaranth.

The area where Palmer amaranth was hand-weeded in 2011 was 3.5 and 15% of the total area scouted in Louisiana and the remaining midsouth, respectively (Table 6). On average, hand-weeding added an additional US$46 and US$59 ha^{-1} to soybean-production input costs in Louisiana and the remaining midsouth, respectively. Palmer amaranth hand-weeding costs as high as US$371 ha^{-1} were reported by some consultants. Currently, hand-weeding laborers charge US$25 h^{-1} to hand-weed Palmer amaranth in Arkansas (Arkansas soybean growers. personal communication), and total hand-weeding cost can vary based on the level of infestation and the frequency of hand-weeding. Palmer amaranth hand-weeding costs of US$49 to US$370 ha^{-1} in cotton and soybean have been reported by others (Sosnoskie and Culpepper 2012; Steckel 2011).

Of the area that was hand-weeded, 57% in Louisiana (3.5% of total area scouted) and 88% in the remaining midsouth (15% of total area scouted) was hand-weeded only once (Table 6). As discussed earlier, less proliferation of glyphosate-resistant Palmer amaranth in Louisiana is the reason behind less hand-weeded area, compared with the remaining midsouth. Interestingly, consultants scouting soybean under heavy infestation of glyphosate-resistant Palmer amaranth reported up to three hand-weedings, even in Louisiana, which suggests that some areas in Louisiana are heavily infested with *Amaranthus* spp. (Palmer amaranth and common waterhemp [*Amaranthus rudis* Sauer]) (Table 6). For all midsouth consultants whose growers opted to hand-weed Palmer amaranth, labor availability followed by size of weed and hand-weeding before weed seed production were the major criteria used to decide whether to hand-remove Palmer amaranth from soybean (data not shown).

Weed Management Research Priorities. In response to the desired research and education priorities for better weed management in soybean, three-fourths of the consultants stipulated the need for management of glyphosate-resistant and glyphosate-tolerant weed species. Out of the total consultants concerned about glyphosate-resistant weed management, 81% indicated the need for better management of glyphosate-resistant Palmer amaranth through more research on determining the most-effective timing for POST control of Palmer amaranth, over-the-top herbicide options other than glyphosate, salvage options for large Palmer amaranth plants, activation of residual herbicides in the absence of rain, tank mixes with residual PRE-applied herbicides, maximum rate of herbicides that can be applied without causing yield losses, proper adjuvant selection for better uptake of herbicides, spraying tips and their coverage for nonglyphosate herbicides, and the effects of deep tillage on glyphosate-resistant Palmer amaranth seed burial. One consultant asked for the screening of current varieties of soybean for tolerance to metribuzin, a 39-yr-old herbicide commonly used for weed control during pre-RR soybean era (Prostko 2010). Realizing the importance of metribuzin to control Palmer amaranth, midsouth researchers have begun to screen current commercial soybean varieties for metribuzin sensitivity (Ross et al. 2011).

The remaining 19% of consultants concerned about the management of glyphosate-resistant or glyphosate-tolerant weed species emphasized more research on the management of weed species other than Palmer amaranth, such as dayflower (*Commelina* spp.), groundcherry (*Physalis* spp.), Texas gourd [*Cucurbita pepo* L. var. *texana* (Scheele) D. Decker], henbit (*Lamium amplexicaule* L.), yellow nutsedge (*Cyperus esculentus* L.), johnsongrass, giant ragweed, horseweed, and Italian ryegrass that escape, resist, or tolerate the nonresidual glyphosate applications.

With no residual activity of glyphosate and glufosinate and overwhelming concern about glyphosate-resistant and glyphosate-tolerant weed species, 31% of consultants desired research that focused on the management of weeds with residual herbicides. Most of those consultants (64%) wanted additional research regarding activation and timing of in-season residual herbicides, but others (41%) asked for research on fall-applied and spring-applied residual herbicides to keep the seedbank of glyphosate-resistant weed species, such as Palmer amaranth, in check. One consultant asked for "a model that can predict breakdown of soybean residual herbicides under different environmental regimes for the appropriate timing of residual herbicide application." Consultants (5%) also suggested more research on preplant-applied residual herbicides, which can provide greater flexibility in planting dates.

Ten percent of the consultants listed research focused on cultural weed-control practices as their top priority. The cultural practices specified by consultants for weed management in soybean were tillage, narrow row-widths, herbicide rotations, and crop rotations, including soybean–corn and soybean–sugarcane (*Saccharum officinarum* L.) under irrigated conditions and soybean–sorghum [*Sorghum bicolor* (L.) Moench ssp. *bicolor*] under dryland farming. They also wanted additional research and training to economically and sustainably decrease the weed seedbank of glyphosate-resistant weed species. In a previous soybean survey, Norsworthy (2003) also expressed the necessity of educating growers about the basics of cultural and mechanical weed control practices.

Additionally, consultants expressed the need to enhance grower awareness about the differences in management practices for existing herbicide-resistant soybean traits. For example, both glyphosate and glufosinate are nonselective and nonresidual herbicides that can be applied over the top of RR and LL soybean, respectively. However unlike glyphosate, glufosinate is a contact herbicide with limited translocation; therefore, its weed control efficacy depends on several factors, including good coverage, relative humidity, and size of weeds (Coetzer et al. 2001; Hoss et al. 2003). In addition, it is very important for the growers to clean spray tanks properly if they are switching between RR and LL soybean systems to avoid crop injury. Educating growers regarding management differences in RR and LL systems and other less-frequently used herbicide-resistant soybean systems will improve weed control and decrease crop injury.

Some consultants (22%) mentioned that additional herbicide modes of action and herbicide-resistant traits are needed to manage the weed species that have evolved resistance to multiple herbicides. There is little possibility of commercialization of a new herbicide mode of action in the next 5 yr, but several new herbicide-resistant traits stacked with glyphosate-resistant, glufosinate-resistant, or both traits may be registered during the next 5 yr, which may allow the use of synthetic auxins (2,4-D and dicamba) and hydroxyphenylpyruvate dioxygenase (HPPD) inhibitors (e.g., isoxaflutole, mesotrione) in soybean (Green and Owen 2011).

In response to the perceived grower obstacles that will limit the adoption of 2,4-D, dicamba, and HPPD-inhibitors, most of the crop consultants were afraid of off-target movement of both synthetic auxins (77%) and HPPD-inhibitors (39%) to nearby susceptible crops, such as cotton, peanut (*Arachis hypogaea* L.), and vegetables. Injury of susceptible crops because of improper sprayer clean out, technology costs, yield drag associated with a new technology, and crop-rotation restrictions were other concerns of consultants that can influence the adoption of synthetic auxin herbicide–resistant and HPPD-inhibitor–resistant traits in midsouth soybean. Similar to off-target movement of herbicide, more consultants were concerned about sprayer clean out in auxin herbicide–resistant soybean traits (12%) compared with HPPD-inhibitor–resistant traits (4%). Four percent of consultants feared the evolution of additional resistant weeds under HPPD-inhibitor–resistant soybean systems, which is a valid concern considering that a population of Palmer amaranth in Kansas has been confirmed resistant to HPPD-inhibiting herbicides (Thompson and Peterson 2012). Interestingly, 11 and 33% of consultants could not think of any impediment in adoption of auxinic herbicide–resistant and HPPD-inhibitor–resistant soybean technologies, respectively, demonstrating three times less concern in adoption of HPPD-inhibitor–resistant compared with auxinic herbicide-resistant soybean traits, provided appropriate stewardship programs and nonchemical strategies are integrated to prevent development of multiple herbicide-resistant weed issues, which could further worsen the problem.

In general, this survey shows that even under weed species shift toward glyphosate-resistant and glyphosate-tolerant weed species, there is reluctance to adopt nonglyphosate-resistant soybean varieties in the midsouth. However, with increasing concern about glyphosate-resistant and glyphosate-tolerant weed species, especially glyphosate-resistant Palmer amaranth, the area under sole use of glyphosate has decreased, and the use of residual herbicides, hand-weeding, and tillage practices is increasing. This survey points out the need to increase consciousness among growers about herbicide-based and nonherbicide-based resistance-management practices in soybean. Compilation is under way for the second part of this survey regarding the rate of adoption and implementation of best resistance-management practices in the midsouth United States.

Acknowledgments

The continued support of weed management research in soybean by the Arkansas Soybean Promotion Board is gratefully appreciated. The authors also appreciate each consultant who took the time to complete the survey.

Literature Cited

Bagavathiannan, M. V., J. K. Norsworthy, K. L. Smith, and N. Burgos. 2011. Seedbank size and emergence pattern of barnyardgrass (Echinochloa crus-galli) in Arkansas. Weed Sci. 59:359–365.

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

Baltazar, A. M. and R. J. Smith Jr. 1994. Propanil-resistant barnyardgrass (*Echinochloa crus-galli*) control in rice (*Oryza sativa*). Weed Sci. 8:576–581.

Benbrook, C. 2009. Impacts of Genetically Engineered Crops on Pesticide Use in the United States: The First Thirteen Years. http://www.organic-center.org/reportfiles/13Years20091126_ExSumFrontMatter.pdf. Accessed: October 2, 2012.

Bonny, S. 2011. Herbicide-tolerant transgenic soybean over 15 years of cultivation: pesticide use, weed resistance, and some economic issues: the case of the USA. Sustainability. 3:1302–1322.

Bradley, J. F. 2000. Economic comparison of weed control systems in conservation tillage systems. Pages 1474–1476 *in* C. P. Dugger and D. A. Richter, eds. Proceedings of the Beltwide Cotton Conference, January 4–8, 2000, San Antonio, TX. Memphis, TN: National Cotton Council of America.

Cardina, J., C. P. Herms, and D. J. Doohan. 2002. Crop rotation and tillage system effects on weed seedbanks. Weed Sci. 50:448–460.

Cerdeira, A. L. and S. O. Duke. 2006. The current status and environmental impacts of glyphosate-resistant crops: a review. J. Environ. Qual. 35:1633–1658.

Coetzer, E., K. Al-Khatib, and T. M. Loughin. 2001. Glufosinate efficacy, absorption, and translocation in amaranth as affected by relative humidity and temperature. Weed Sci. 49:8–13.

Culpepper, A. S., A. C. York, R. B. Batts, and K. M. Jennings. 2000. Weed management in glufosinate- and glyphosate-resistant soybean (*Glycine max*). Weed Technol 14:77–88.

DeVore, J. D., J. K. Norsworthy, and K. Brye. 2013. Influence of deep tillage, a rye cover crop, and various soybean production systems on Palmer amaranth emergence in soybean. Weed Technol. doi:10.1614/WT-D-12-00125.1.

Fernandez-Cornejo, J. and M. Caswell. 2006. The first decade of genetically engineered crops in the United States. Washington, DC: U.S. Department of Agriculture, Economic Research Service, Economic Information Bulletin No. 11.

Green, J. M. and M. D. K. Owen. 2011. Herbicide-resistant crops: utilities and limitations for herbicide-resistant weed management. J. Agric. Food Chem. 59:5819–5829.

Griffin, J. W. and E. P. Webster. 2012. Fighting Weeds in Louisiana Agriculture for 125 years. http://text.lsuagcenter.com/en/communications/publications/agmag/Archive/2012/Spring/. Accessed: October 18, 2012.

Hammond, E. 2010. Genetically Engineered Backslide: The Impact of Glyphosate-Resistant Palmer Pigweed on Agriculture in the United States. Penang, Malaysia: Third World Network, TWN Biotechnology and BioSafety Series 12. Pp. 1–22

Heap, I. 2012. The International Survey of Herbicide Resistant Weeds. http://www.wssa.net. Accessed: September 1, 2012.

Horowitz, J., R. Ebel, and K. Ueda. 2010. "No-Till" Farming is a Growing Practice. Washington, DC: United States Department of Agriculture, Economic Research Service, Economic Information Bulletin 70.

Hoss, N. E., K. Al-Khatib, D. E. Peterson, and T. M. Loughin. 2003. Efficacy of glyphosate, glufosinate, and imazethapyr on selected weed species. Weed Sci. 51:110–117.

Hurley, T. M., P. D. Mitchell, and G. B. Frisvold. 2009. Weed management costs, weed best management practices, and the Roundup Ready® weed management program. Agbioforum. 12:281–290.

Jha, P. and J. K. Norsworthy. 2009. Soybean canopy and tillage effects on emergence of Palmer amaranth (*Amaranthus palmeri*) from a natural seed bank. Weed Sci. 57:644–651.

Jordan, D. L., A. C. York, J. L. Griffin, P. A. Clay, P. R. Vidrine, and D. B. Reynolds. 1997. Influence of application variables on efficacy of glyphosate. Weed Technol. 11:354–362.

Koger, C. H., D. H. Poston, R. M. Hayes, and R. F. Montgomery. 2004. Glyphosate-resistant (*Conyza canadensis*) horseweed in Mississippi. Weed Technol. 18:820–825.

Kruger, G. R., W. G. Johnson, S. C. Weller, M. D. K. Owen, D. R. Shaw, J. W. Wilcut, D. L. Jordan, R. G. Wilson, M. L. Bernards, and B. G. Young. 2009. U.S. grower views on problematic weeds and changes in weed pressure in glyphosate-resistant corn, cotton, and soybean cropping systems. Weed Technol. 23:162–166.

Lovelace, M. L. 2003. Implications of Quinclorac Use in Arkansas: Impacts of Quinclorac Drift on Tomato Physiology and Development of Quinclorac Resistance in Barnyardgrass. Ph.D dissertation. Fayetteville, AR: University of Arkansas. Pp. 70–71.

Mueller, T. C., P. D. Mitchell, B. G. Young, and A. S. Culpepper. 2005. Proactive versus reactive management of glyphosate-resistant or -tolerant weeds. Weed Technol. 19:924–933.

Nandula, V. K., K. N. Reddy, C. H. Koger, D. H. Poston, A. M. Rimando, S. O. Duke, J. A. Bond, and D. N. Ribeiro. 2012. Multiple resistance to glyphosate and pyrithiobac in Palmer amaranth (*Amaranthus palmeri*) from Mississippi and response to flumiclorac. Weed Sci. 60:179–188.

Neve, P., A. J. Diggle, F. P. Smith, and S. B. Powles. 2003. Simulating evolution of glyphosate resistance in *Lolium rigidum* I: population biology of a rare resistance trait. Weed Res. 43:404–417.

Neve, P., J. K. Norsworthy, K. L. Smith, and I. A. Zelaya. 2011. Modelling evolution and management of glyphosate resistance in *Amaranthus palmeri*. Weed Res. 51:99–112.

Nichols, R. L., J. Bond, and A. S. Culpepper, et al. 2009. Glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*) spreads in the Southern United States. Resist. Pest Manag. Newsl. 18:8–10.

Norsworthy, J. K. 2003. Use of soybean production surveys to determine weed management needs of South Carolina farmers. Weed Technol. 17:195–201.

Norsworthy, J. K. 2008. Effect of tillage intensity and herbicide programs on changes in weed species density and composition in the southeastern coastal plains of the United States. Crop Prot. 27:151–160.

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

Norsworthy, J. K., M. V. Bagavathiannan, P. Neve, K. Smith, and I. Zelaya. 2011. Integrating nonchemical practices into simulation modeling for herbicide resistance: a proactive strategy. Abstract 226 *in* Proceedings of the Annual Meeting of the Weed Science Society of America, February 7–11, 2011, Portland, OR. Champaign, IL: WSSA.

Norsworthy, J. K., G. M. Griffith, R. C. Scott, K. L. Smith, and L. R. Oliver. 2008. Confirmation and control of glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*) in Arkansas. Weed Technol. 22:108–113.

Norsworthy, J. K., R. Scott, K. Smith, J. Still, L. E. Estorninos Jr., and S. Bangarwa. 2009. Confirmation and management of clomazone-resistant barnyardgrass in rice. Abstract 211 *in* Proceedings of the Southern Weed Science Society, Orlando, FL, Volume 62.

Norsworthy, J. K., K. L. Smith, R. C. Scott, and E. E. Gbur. 2007. Consultant perspectives on weed management needs in Arkansas cotton. Weed Technol. 21:825–831.

Norsworthy, J. K., S. M. Ward, D. R. Shaw, R. S. Llewellyn, R. L. Nichols, T. M. Webster, K. W. Bradley, G. Frisvold, S. B. Powles, N. R. Burgos, W. W. Witt, and M. Barrett. 2012. Reducing the risks of herbicide resistance: best management practices and recommendations. Weed Sci. Special Issue. Pp. 31–62.

[NRC] National Research Council. 2010. Impact of Genetically-Engineered Crops on Farm Sustainability in the United States. Washington, DC: The National Academies Press.

Osunsami, S. 2009. Killer Pigweeds Threaten Crops in the South. http://abcnews.go.com/WN/pig-weed-threatens-agriculture-industryovertaking-fields-crops/story?id=8766404. Accessed: October 1, 2012.

Prince, J. M., D. R. Shaw, W. A. Givens, M. E. Newman, M.D.K. Owen, S. C. Weller, B. G. Young, R. G. Wilson, and D. L. Jordan. 2012a. Benchmark Study: III. Survey on changing herbicide use patterns in glyphosate-resistant cropping systems. Weed Technol. 26:536–542.

Prince, J. M., D. R. Shaw, W. A. Givens, M.D.K. Owen, S. C. Weller, B. G. Young, R. G. Wilson, and D. L. Jordan. 2012b. Benchmark study, I: introduction, weed population, and management trends from the benchmark survey 2010. Weed Technol. 26:525–530.

Prostko, E. 2010. Consider Metribuzin in Soybeans. http://magissues.farmprogress.com/STF/SF05May10/stf009.pdf. Assessed: October 16, 2012.

Reddy, K. N. and J. K. Norsworthy. 2010. Glyphosate-resistant crop production systems: impact on weed species shifts. Pages 165–184 *in* V. K. Nandula, ed. Glyphosate Resistance in Crops and Weeds: History, Development, and Management. Singapore: J. Wiley.

Riar, D. S., J. K. Norsworthy, J. A. Bond, M. T. Bararpour, M. J. Wilson, and R. C. Scott. 2012. Resistance of *Echinochloa crus-galli* populations to acetolactate synthase-inhibiting herbicides. Intl. J. Agron. doi:10.1155/2012/893953.

Riar, D. S., J. K. Norsworthy, and G. M. Griffith. 2011a. Herbicide programs for enhanced glyphosate-resistant and glufosinate-resistant cotton (*Gossypium hirsutum*). Weed Technol. 25:526–534.

Riar, D. S., J. K. Norsworthy, D. B. Johnson, R. C. Scott, and M. Bagavathiannan. 2011b. Glyphosate resistance in a johnsongrass (*Sorghum halepense*) biotype from Arkansas. Weed Sci. 59:299–304.

Riar, D. S., J. K. Norsworthy, V. Srivastava, V. Nandula, J. A. Bond, and R. C. Scott. 2013. Physiological and molecular basis of acetolactate synthase-inhibiting herbicide resistance in barnyardgrass (*Echinochloa crus-galli*). J. Agri. Food Chem. 61:278–289.

Ross, J., T. Eubank, J. K. Norsworthy, and R. C. Scott. 2011. 2011 Soybean Variety Screening for Metribuzin Sensitivity. University of Arkansas Division of Agriculture, Cooperative Extension Service. http://www.mississippi-crops.com/wp-content/uploads/2012/03/UofA-2011-Metribuzin-Screening-Final.pdf. Accessed: October 2, 2012.

Scott, R. C., J. W. Boyd, G. Selden, J. K. Norsworthy, and N. Burgos. 2013. Recommended Chemicals for Weed and Brush Control. Little Rock, AR: The University of Arkansas Division of Agriculture Cooperative Extension Service, Miscellaneous Publication 44. Pp 36.

Shaner, D. L. 2000. The impact of glyphosate-resistant crops on the use of other herbicides and resistance management. Pest Manag Sci. 56:320–326.

Sosnoskie, L. M. and S. Culpepper. 2012. 2012: Changes in cotton weed management practices in Georgia following the development of glyphosate-resistant Palmer amaranth. Proc. 2012 Beltwide Cotton Conference. Web page: http://www.gaweed.com/slides/beltwide-sosnoskiesurvey/beltwide-sosnoskiesurvey.pdf. Accessed: October 2, 2012.

Steckel, L. E. 2011. Glyphosate-resistant weeds: lessons learned in Tennessee. *In:* Proceedings of the 2011 Crop Pest Management Shortcourse & Minnesota Crop Production Retailers Trade Show. http://www.extension.umn.edu/AgProfessionals/components/CPM/2011/Steckel.pdf. Accessed: October 2, 2012.

Steckel, L. E., C. L. Main, A. T. Ellis, and T. C. Mueller. 2008. Palmer amaranth (*Amaranthus palmeri*) in Tennessee has low level glyphosate resistance. Weed Technol. 22:119–123.

Tharp, B. E. and J. J. Kells. 2002. Residual herbicides used in combination with glyphosate and glufosinate in corn (*Zea mays*). Weed Technol. 16:274–281.

Thompson, C. and D. Peterson. 2012. A Palmer amaranth population resistant to HPPD herbicides. Abstract 68-1 *in:* Visions for a Sustainable Plant: Proceedings of the American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America International Annual Meetings, October 21–24, 2012, Cincinnati, OH. Madison, WI: ASA, CSSA, and SSSA.

[USDA-NASS] United States Department of Agriculture, National Agricultural Statistics Service. 2012. Acreage: http://www.usda.gov/nass/PUBS/TODAYRPT/acrg0612.pdf. Accessed: October 2, 2012.

[USDA-NRCS] United States Department of Agriculture, National Resource Conservation Service. 2000. Residue Management in No-Till. Washington, DC: Natural Resource Conservation Service Tennessee Jobsheet 329A.

Vencill, W. K., R. L. Nichols, T. M. Webster, J. K. Soteres, C. Mallory-Smith, N. R. Burgos, W. G. Johnson, and M. R. McClelland. 2012. Herbicide resistance: toward an understanding of resistance development and the impact of herbicide-resistant crops. Weed Sci. 2012 Special Issue. Pp. 2–30.

Webster, T. M. and G. E. MacDonald. 2001. A survey of weeds in various crops in Georgia. Weed Technol. 15:771–790.

Webster, T. M. and L. M. Sosnoskie. 2010. Loss of glyphosate efficacy: a changing weed spectrum in Georgia cotton. Weed Sci. 58:73–79.

Received November 16, 2012, and approved February 5, 2013.