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Consultant Perspectives on Weed Management Needs in Midsouthern United States Cotton: A Follow-Up Survey

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A survey questionnaire was sent to cotton consultants of Arkansas and Mississippi through direct mail and Louisiana and Tennessee consultants through on-farm visits in fall of 2011. The survey was returned by a total of 22 Arkansas, 17 Louisiana, 10 Mississippi, and 11 Tennessee cotton consultants, representing 26, 53, 13, and 38% of total cotton planted in these states in 2011, respectively. Collectively, the area planted to glyphosate-resistant (Roundup Ready®, RR) cotton was 97%, glyphosate plus glufosinate-resistant (Widestrike® Flex, WRF) cotton was 30%, and glufosinate-resistant (Liberty Link, LL) cotton was 2.6% of the total cotton surveyed in 2011. Seventy percent of area in all states is still under continuous RR/WRF cotton. Average cost of herbicides in RR systems was \$114 ha^{-1} and in LL systems was \$137 ha^{-1}. Across the states, cotton planted under no-tillage, conservation tillage, and conventional tillage was 31, 36, and 33%, respectively, of total scouted cotton. Area under conventional tillage increased and conservation tillage decreased in Arkansas compared with a previous survey conducted in 2006. Palmer amaranth, morningglories, and horseweed in the order of listing were the most problematic weeds of cotton across Arkansas, Mississippi, and Tennessee. In Louisiana, however, morningglories were the most problematic weed followed by Palmer amaranth and common waterhemp. Glyphosate-resistant (GR) Palmer amaranth infested only 13% of scouted cotton area in Louisiana compared with 75% in the remaining three states, and consequently, hand-weeding to control GR Palmer amaranth is practiced on only 2.5% of total scouted area of Louisiana and 49% of the scouted area of the remaining three states. Hand-weeding added an additional \$12 to 371 ha^{-1} to weed-management costs. One-half (50%) of the cotton consultants emphasized the need for more research on residual herbicides that can control GR Palmer amaranth effectively.

Nomenclature: Glufosinate; glyphosate; common waterhemp, *Amaranthus rudis* Sauer; horseweed, *Conyza canadensis* L. Cronq.; morningglories, *Ipomoea* spp.; Palmer amaranth, *Amaranthus palmeri* (S.) Wats.; cotton, *Gossypium hirsutum* L.

Key words: Glyphosate-resistant cotton, residual herbicides, tillage, weed management survey, weed species shift.

Se envió una encuesta a consultores en producción de algodón de Arkansas y Mississippi mediante correo directo y de Louisiana y Tennessee mediante visitas en finca en el otoño 2011. La encuesta fue completada y devuelta por 22 consultores de Arkansas, 17 de Louisiana, 10 de Mississippi, y 11 de Tennessee, lo que representó 26, 56, 13, y 38% del total del área sembrada con algodón en estos estados en 2011, respectivamente. Colectivamente, el área sembrada con algodón resistente a glyphosate (Roundup Ready®, RR) fue 97%, resistente a glyphosate más glufosinate (Widestrike® Flex, WRF) fue 30%, y resistente a glufosinate (Liberty Link, LL) fue 2.6% del total de la muestra en 2011. El 70% del área en todos los estados está todavía bajo algodón RR/WRF continuo. El costo promedio de los herbicidas en sistemas RR fue \$114 ha^{-1} y en sistemas LL fue \$137 ha^{-1}. Entre todos los estados, el algodón sembrado bajo labranza cero, labranza de conservación, y labranza convencional fue 31, 36, y 33%, respectivamente, del total del algodón muestreado. El área con labranza convencional incrementó y con labranza de conservación disminuyó en Arkansas al compararse con la encuesta anterior realizada en 2006. Las malezas *Amaranthus palmeri*, *Ipomoea* spp., y *Conyza canadensis* fueron las más problemáticas en orden de mención, en Arkansas, Mississippi, y Tennessee. En Louisiana, sin embargo, *Ipomoea* spp. fueron las más problemáticas seguidas por *A. palmeri* y *Amaranthus rudis*. *A. palmeri* resistente a glyphosate (GR) infestó solamente 13% del área de algodón evaluada en Louisiana, comparado con 75% en los otros tres estados, y consecuentemente, el control manual de *A. palmeri* GR fue practicado en solamente 2.5% del total del área evaluada de Louisiana y 49% del área en los otros tres estados. La deshierba manual agregó un costo adicional al manejo de malezas de \$12 a 371 ha^{-1}. La mitad (50%) de los consultores en producción de algodón hicieron énfasis en la necesidad de que haya más investigación sobre herbicidas residuales para el control efectivo de *A. palmeri* GR.

Glyphosate-resistant (Roundup Ready® [RR], Monsanto) crop technologies reduced the use of other weed management technologies in midsouthern U.S. cotton and soybean [*Glycine max* (L.) Merr.] production. Since the commercialization of RR soybean in 1996 and cotton in 1997, the area under these technologies has increased tremendously (Green and Owen 2011). A recent survey regarding general weed management practices of soybean in the midsouthern United States reported that 93% of the scouted soybean area was planted with RR soybean and remaining scouted area was planted

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with glufosinate-resistant (Liberty Link® [LL], Bayer CropScience) soybean (Riar et al. 2013). According to a 2006 survey of cotton consultants to assess weed management practices in Arkansas cotton, 98% of the total cotton hectares in Arkansas were planted to RR and RR Flex (enhanced glyphosate-resistant) cotton cultivars (Norsworthy et al. 2007).

Overreliance on glyphosate, however, has caused weed species shifts to glyphosate-tolerant (Jordan et al. 1997; Norsworthy and Oliver 2002; Riar et al. 2011a) and -resistant (GR) (Dickson et al. 2011; Heap 2013; Kruger et al. 2009; Nandula et al. 2012; Norsworthy et al. 2008; Prince et al. 2012a; Steckel et al. 2008) weed species. Morningglories have an inherent tolerance to glyphosate (Riar et al. 2011a), but horseweed and Palmer amaranth resistant to glyphosate were documented in Arkansas in 2003 and 2006, respectively (Heap 2013; Norsworthy et al. 2008). Accordingly, in the 2006 cotton consultant survey, horseweed, Palmer amaranth, and morningglories in the order of listing were the most problematic weeds of cotton in Arkansas (Norsworthy et al. 2007).

Weed management programs in the midsouthern states have placed tremendous emphasis on controlling and minimizing the spread of GR Palmer amaranth (Norsworthy et al. 2008; Steckel et al. 2008). Widespread prevalence of resistance to acetolactate synthase (ALS)-inhibiting herbicides in the midsouthern United States has rendered control of GR Palmer amaranth ineffective in cotton with ALS-inhibiting herbicides such as trifloxysulfuron and pyrithiobac (Norsworthy et al. 2008). However, evolution of resistance to glyphosate in horseweed and Palmer amaranth has made growers of the southern United States more aware and concerned about management of GR weed species, and subsequently, the use of tillage, residual herbicides, and hand-weeding has increased to control glyphosate-resistant and -tolerant weed species (Hammond 2010; Norsworthy et al. 2012; Prince et al. 2012b; Riar et al. 2013).

Consultants have first-hand information regarding common constraints to crop production and weed management. During the 2006 Arkansas cotton survey, consultants requested more research to control herbicide-resistant weeds with residual and nonresidual herbicides and to determine the long-term impact of RR Flex cotton on weed shifts (Norsworthy et al. 2007). Additionally, they requested educational efforts aimed at encouraging the adoption of herbicide-resistant weed management strategies. Keeping in view the outcomes of the 2006 survey of Arkansas cotton consultants and expected changes in the weed management practices because of GR Palmer amaranth, a weed management survey was constructed for cotton consultants of Arkansas and three other midsouthern states (Louisiana, Mississippi, and Tennessee) to determine the current weed management and cotton production practices, troublesome weed species, and spread and management of GR Palmer amaranth in midsouthern U.S. cotton.

Materials and Methods

A follow-up survey to the one conducted in 2006 (Norsworthy et al. 2007) was constructed and directly mailed to all registered crop consultants from Arkansas (255) and Mississippi (66), and hand-delivered to randomly selected cotton consultants from Louisiana (61) and Tennessee (25). Registered crop consultants' names and addresses were obtained from the Agricultural Consultants' Associations of Arkansas, Louisiana, Mississippi, and Tennessee in fall 2011. The list provided by Agricultural Consultants' Associations did not specify consultants by crop. Therefore, the survey in Arkansas and Mississippi was sent to all consultants and in Louisiana and Tennessee hand-delivered to known cotton consultants selected randomly.

The survey questionnaire was similar to the questionnaire sent to soybean consultants during the fall 2011 survey of soybean consultants (Riar et al. 2013). Two additional questions included in the current survey were: percent cotton hectares planted to varieties resistant to glyphosate and lepidopteran pests with some level of resistance to glufosinate (Widestrike® Flex [WRF], PhytoGen Seed Company) and percent WRF cotton hectares treated with glufosinate over the top of the crop.

The survey was composed of four sections titled: Cotton Weed Control Focus, General Weed Management Questions, Herbicide Resistance, and Glyphosate-Resistant Palmer Amaranth. In the first section, consultants were asked to list two research priorities for university researchers to undertake. Along with general weed management questions in the second section, consultants were also asked to rate a list of 40 potentially problematic weeds on a scale of 1 to 5, with 1 = not important, 2 = rarely important, 3 = occasionally important, 4 = important, and 5 = very important. Additionally, they were 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. The third section of the survey will be summarized in another manuscript focused at understanding the adoption of herbicide management strategies and limitations to the adoption of these practices in cotton, rice (*Oryza sativa* L.), and soybean. The fourth section comprised questions related to the spread and management of GR Palmer amaranth.

Three, two, and one problematic point(s) were assigned to the first, second, and third most problematic weeds, respectively, and problematic ranking was calculated on the basis of average problematic points attained by each weed species by state and collectively over four states (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. Also, state and collective importance rankings of all listed weed species were calculated on the basis of the point values assigned by consultants. Standard error of mean for problematic and importance points was also calculated for each weed species to assess variation in consultants' responses.

Results and Discussion

Cotton Area Scouted. Of all cotton consultants to whom the survey questionnaire was mailed or delivered, 22 from Arkansas, 17 from Louisiana, 10 from Mississippi, and 11

Table 1. General weed management practices by state and collectively in midsouthern U. S. (Arkansas [AR] + Louisiana [LA] + Mississippi [MS] + Tennessee [TN]) glyphosate- (RR) and glufosinate-resistant (LL) cotton.

General weed management questions	Midsouthern United States ($n = 60$)	AR ($n = 22$)	LA ($n = 17$)	MS ($n = 10$)	TN ($n = 11$)
Total scouted hectares reported	241,660	70,780	62,990	31,810	76,080
Percentage of total cotton planted in 2011	28	26	53	13	38
Area under glyphosate-resistant (RR) cotton (% of total scouted hectares)	97	96	99	95	97
RR cotton rotated with non-RR crop during last 3 yr (% of total scouted hectares)	11	11	8.5	17	12
Did growers plant RR cotton continuously over the last 5 yr (% consultants saying yes)	87	86	82	70	100
Area under continuous RR cotton over the last 5 years (% of total scouted hectares)	70	73	63	60	78
Area treated with glyphosate excluding burndown (% of total scouted hectares)	94	90	99	92	96
Area solely treated with glyphosate (% of RR cotton-scouted hectares)	9.3	16	9.1	2.3	6.1
Area treated with a PRE herbicide followed by glyphosate (% of RR cotton-scouted hectares)	81	86	63	80	90
Area under glufosinate-resistant (LL) cotton (% of total scouted hectares)	2.6	2.9	1.1	4.5	2.9
Area under cotton varieties with resistance to glyphosate and some tolerance to glufosinate (WRF) (% of total scouted hectares)	30	7.8	12	11	73
WRF area treated with glufosinate (% of widestrike cotton hectares)	75	74	44	90	75
Area solely treated with glufosinate (% of LL cotton-scouted hectares)	13	29	27	14	0
Area treated with a PRE herbicide followed by glufosinate (% of LL + Widestrike cotton-scouted hectares)	60	50	12	59	68
Average cost of weed control in glyphosate-based cotton systems					
Average ($ ha^{-1}) with min to max range	114 (30 to 247)	128 (30 to 210)	96 (49 to 136)	81 (54 to 111)	142 (72 to 247)
Maximum ($ ha^{-1}) with min to max range	171 (40 to 430)	194 (40 to 430)	140 (74 to 210)	135 (77 to 247)	200 (121 to 334)
Average cost of weed control in glufosinate-based cotton systems					
Average ($ ha^{-1}) with min to max range	137 (37 to 309)	149 (86 to 210)	154 (124 to 185)	98 (74 to 124)	148 (37 to 309)
Maximum ($ ha^{-1}) with min to max range	181 (104 to 371)	198 (111 to 247)	192 (173 to 210)	127 (104 to 153)	199 (124 to 371)

from Tennessee returned valid surveys. These consultants represented 70,780 (26%) of a total 275,300 cotton hectares planted in Arkansas, 62,990 (53%) of a total 119,400 cotton hectares planted in Louisiana, 31,810 (13%) of a total 255,000 cotton hectares planted in Mississippi, and 76,080 (38%) of a total 200,400 cotton hectares planted in Tennessee in 2011 (USDA-NASS 2012).

General Weed Management Practices. Of the total scouted area, the area planted to RR cotton varieties was 96% in Arkansas, 99% in Louisiana, 95% in Mississippi, 97% in Tennessee, and 97% overall in the four states (Table 1). Most of the remaining area in these states (2.9% in Arkansas, 1.1% in Louisiana, 4.5% in Mississippi, and 2.9% in Tennessee) was planted with LL cotton. There was only a 2% decrease in area under RR cotton in Arkansas compared with the 2006 survey (Norsworthy et al. 2007), indicating that evolution of GR weeds from 2006 through 2011 did little to deter cotton growers from growing RR cotton.

On the basis of a recent soybean survey, adoption of LL cotton was similar to the adoption of LL soybean in Louisiana, Mississippi, and Tennessee, but was far less in Arkansas (2.9% LL cotton [Table 1] vs. 12% LL soybean [Riar et al. 2013]) because of the lack of adaptable LL cotton varieties that yield similarly to RR cotton in Arkansas (Bourland et al. 2009). Collectively in all four states (referred to as midsouthern United States), only 11% of the reported scouted cotton hectares reported rotating RR cotton with a non-RR crop during the last 3 yr and 70% of the reported area was under continuous RR cotton from 2006 through 2011 (Table 1). Hence, there is an urgent need to educate growers and consultants regarding rotation of herbicide mechanisms of action and other best management practices to reduce the intensity of selection for herbicide resistance.

Ninety four percent of the scouted midsouthern U.S. cotton was treated with glyphosate, excluding burndown, and 9% of the scouted RR cotton was treated solely with glyphosate (Table 1). Glufosinate was used solely on 13% of the scouted LL cotton hectares. Sole use of glufosinate compared with the use of glufosinate along with residual herbicides could lead to faster evolution of glufosinate-resistant weeds. Neither glyphosate nor glufosinate has residual soil activity, and their efficacy decreases when applied to large plants. Moreover, evolution of GR Palmer amaranth imposes an immense need for use of residual herbicides in RR and LL cotton systems (Riar et al. 2011a; Shaw and Arnold 2002).

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Table 2. Consultants' perspective on percent area under different tillage practices by states and collectively in midsouthern U.S. (Arkansas [AR] + Louisiana [LA] + Mississippi [MS] + Tennessee [TN]) cotton.

Tillage type	Midsouthern United States ($n = 60$)	AR ($n = 22$)	LA ($n = 17$)	MS ($n = 10$)	TN ($n = 11$)
	% of total scouted				
No-tillage	31	19	8.0	21	68
Conservation tillage (stale seedbed)	36	46	60	29	7.2
Conventional tillage	33	35	32	50	25
Row cultivation	3.4	5.5	1.7	8.8	0.69
Deep tillage	3.0	0.77	10	0.0	0.37

The use of PRE residual herbicides in scouted LL and WRF cotton (60% of scouted LL plus WRF cotton area) was less than in RR cotton (81% of scouted RR area) (Table 1), which could have been due to growers' perception that timely applications of glufosinate can effectively control GR Palmer amaranth. Nevertheless, less use of PRE residual herbicides can impose a great risk of glufosinate resistance evolution in LL cotton systems (Riar et al. 2011a). Interestingly, the use of residual herbicides by growers was greater in RR cotton than in RR soybean systems (61%, Riar et al. 2013), which was likely due to the lack of an effective over-the-top herbicide option for control of GR and ALS-resistant Palmer amaranth in cotton (Norsworthy et al. 2008). Conversely, GR and ALS-resistant Palmer amaranth control can still be achieved in RR soybean systems through use of properly timed over-the-top applications of protoporphyrinogen oxidase (PPO)-inhibiting herbicides (Scott et al. 2012). Averaged over states, the cost of herbicides in RR cotton systems was \$114 ha^{-1} and in LL cotton systems was \$137 ha^{-1}. The cost of herbicide application in scouted RR cotton fields with dense infestations of GR Palmer amaranth were up to \$430 ha^{-1}.

Integrated programs with PRE residual herbicides and tillage were the only means to successfully grow cotton before the adoption of RR technology (Barnes and Whitmore 1990). However, effective weed management with herbicide-resistant technologies, especially RR technology, brought changes in tillage practices in the later 1990s, including a decline in conventional tillage and an increase in conservation tillage and no-tillage across the midsouthern United States. According to a 2006 survey of tillage trends following the adoption of RR crops, 46% of growers utilizing continuous RR cotton systems shifted from conventional to conservation tillage and no-tillage (Givens et al. 2009).

After commercialization of RR cotton, no-tillage increased in areas such as western Tennessee (three- to eightfold greater area under no-tillage in Tennessee compared with the remaining three states [Table 2]) where soil erosion due to wind or rainstorms was a major problem (Mueller et al. 2005). However, because of no option for row cultivation in no-tillage production systems, lack of irrigation ($<$ 5% in 2011) to incorporate residual herbicides (Vebree 2013), and the need for an effective POST herbicide option in areas heavily infested with GR Palmer amaranth, the area under WRF cotton cultivars was much greater in Tennessee (73%) compared with the remaining three states (8 to 12%) (Table 1).

In 2006, tillage practices in Arkansas cotton were characterized as: conventional tillage on 20%, conservation tillage on 63%, and no-tillage systems on 17% of the total scouted area (Norsworthy et al. 2007). The current survey depicted that in Arkansas and Mississippi, area under conventional tillage is 35 and 50% of the total scouted cotton, respectively, and conservation tillage was 46 and 29% of total scouted cotton, respectively (Table 2). Comparing the results of the current survey with earlier cotton surveys by Givens et al. (2009) and Norsworthy et al. (2007), it is apparent that tillage intensity has increased in recent years, presumably because of the widespread occurrence of GR weeds, most notably GR Palmer amaranth. Price et al. (2011) also reported that cotton area under conservation tillage increased steeply from 1996 to 2004 and remained steady from 2004 to 2008, but after GR Palmer amaranth evolution and spread, area under conservation tillage is at risk to be converted back to high-intensity conventional tillage systems. Fortunately, midsouthern U.S. growers are using deep tillage and row cultivation (both part of conventional tillage) as a resistance management technique in their weed management programs (Norsworthy et al. 2012). Deep tillage reduces Palmer amaranth emergence and exhausts weed seeds by burying them up to a depth of 30 cm and row cultivation reduces the intensity of selection for herbicide-resistant biotypes (DeVore et al. 2013; Neve et al. 2011).

Problem Weeds. Collectively in all four states, Palmer amaranth, morningglories, and horseweed were first, second, and third most problematic weeds (Table 3). Although the top three problematic weeds in the 2006 survey conducted by Norsworthy et al. (2007) remained unchanged in the current survey, the order of problematic ranking did change. In the 2006 survey, horseweed was ranked first and Palmer amaranth was the second most problematic and important weed of cotton. Horseweed gained first rank in the list of problematic weeds of the 2006 survey because of its evolution of resistance to glyphosate; however, GR horseweed is not as competitive with cotton as Palmer amaranth (Rowland et al. 1999), and evolution of glyphosate resistance in Palmer amaranth made it the most problematic weed of cotton in the most recent survey. Accordingly, importance ranking of horseweed dropped to fifth in the current survey. Continuous RR cotton cultivation and the inherent tolerance of morningglories to glyphosate (Riar et al. 2011a) is reason for this weed to continue its prominence in cotton. On the basis of the importance metric, johnsongrass [*Sorghum halepense* (L.) Pers.] was ranked the second most important weed overall in this region, which may be partially attributed to existence of GR johnsongrass in Arkansas, Mississippi, and Louisiana (Heap 2013; Riar et al. 2011b) and the prevalence of this

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Table 3. Consultants' ranking of weeds of cotton in the midsouthern United States (data from Arkansas [$n = 22$], Louisiana [$n = 17$], Mississippi [$n = 10$], and Tennessee [($n = 11$]) combined, along with top five most problematic weeds of these states.

Common name	Scientific name	Problematic points (SEM)[a]	Problematic rank	Importance points (SEM)[b]	Importance rank
Palmer amaranth	*Amaranthus palmeri* (S.) Wats.	2.27 (0.16)	1	4.66 (0.10)	1
Morningglories	*Ipomoea* spp.	1.20 (0.13)	2	4.16 (0.14)	3
Horseweed	*Conyza canadensis* (L.) Cronq.	0.60 (0.12)	3	3.92 (0.16)	5
Annual grasses[c]	—	0.33 (0.09)	4	—	—
Italian ryegrass	*Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot	0.22 (0.09)	5	3.41 (0.16)	7
Common waterhemp	*Amaranthus rudis* Sauer	0.15 (0.07)	6	2.69 (0.17)	15
Prickly sida	*Sida spinosa* L.	0.13 (0.07)	7	3.17 (0.15)	10
Barnyardgrass	*Echinochloa crus-galli* (L.) Beauv.	0.12 (0.06)	8	3.54 (0.16)	6
Henbit	*Lamium amplexicaule* L.	0.12 (0.06)	8	3.93 (0.15)	4
Browntop millet	*Brachiaria ramosa* (L.) Stapf	0.12 (0.07)	8	1.90 (0.16)	30
Yellow nutsedge	*Cyperus esculentus* L.	0.12 (0.06)	8	3.54 (0.14)	6
Crabgrass	*Digitaria* spp.	0.10 (0.07)	9	3.19 (0.15)	9
Sicklepod	*Senna obtusifolia* (L.) H.S. Irwin & Barneby	0.10 (0.05)	9	2.92 (0.16)	12
Redvine	*Brunnichia ovata* (Walt.) Shinners	0.10 (0.06)	9	2.86 (0.14)	14
Hemp sesbania	*Sesbania herbacea* (P. Mill.) McVaugh	0.08 (0.04)	10	3.08 (0.16)	11
Goosegrass	*Eleusine indica* (L.) Gaertn.	0.08 (0.05)	10	2.68 (0.16)	16
Spotted spurge	*Chamaesyce maculata* (L.) Small	0.05 (0.04)	11	2.10 (0.13)	26
Smartweeds	*Polygonum* spp.	0.03 (0.03)	12	2.86 (0.15)	14
Common cocklebur	*Xanthium strumarium* L.	0.03 (0.03)	12	1.92 (0.12)	29
Annual bluegrass	*Poa annua* L.	0.03 (0.02)	12	2.90 (0.17)	13
Giant ragweed	*Ambrosia trifida* L.	0.02 (0.02)	13	2.64 (0.15)	17
Johnsongrass[d]	*Sorghum halepense* (L.) Pers.	0.02 (0.02)	13	4.34 (0.10)	2
Broadleaf signalgrass	*Urochloa platyphylla* (Nash) R.D. Webster	0	—	3.25 (0.14)	8
Fall panicum	*Panicum dichotomiflorum* Michx.	0	—	2.39 (0.15)	21
Northern jointvetch	*Aeschynomene virginica* (L.) B.S.P.	0	—	1.92 (0.15)	29
Red rice	*Oryza sativa* L.	0	—	2.10 (0.19)	26
Hophornbeam copperleaf	*Acalypha ostryifolia* Riddell	0	—	2.32 (0.13)	22
Common lambsquarters	*Chenopodium album* L.	0	—	1.95 (0.12)	28
Groundcherries	*Physalis* spp.	0	—	2.10 (0.14)	26
Dayflower	*Commelina diffusa* Burm. f.	0	—	1.90 (0.14)	30
Cutleaf evening-primrose	*Oenothera laciniata* Hill	0	—	2.68 (0.15)	16
Eclipta	*Eclipta prostrata* (L.) L.	0	—	1.83 (0.13)	31
Curly dock	*Rumex crispus* L.	0	—	2.25 (0.13)	23
Chickweed	*Cerastium* and *Stellaria* spp.	0	—	2.17 (0.15)	24
Carolina geranium	*Geranium carolinianum* L.	0	—	2.47 (0.14)	19
Common purslane	*Portulaca oleracea* L.	0	—	2.42 (0.13)	20
Shepherd's-purse	*Capsella bursa-pastoris* (L.) Medik.	0	—	2.02 (0.12)	27
Common ragweed	*Ambrosia artemisiifolia* L.	0	—	2.15 (0.11)	25
Spurred anoda	*Anoda cristata* (L.) Schlecht.	0	—	2.10 (0.13)	26
Bermuda grass	*Cynodon dactylon* (L.) Pers.	0	—	2.47 (0.13)	19
Velvetleaf	*Abutilon theophrasti* Medik.	0	—	2.63 (0.14)	18
Top five problematic weeds of Arkansas					
Palmer amaranth	*Amaranthus palmeri* (S.) Wats.	3.00 (0.00)	1	5.00 (0.00)	1
Morningglories	*Ipomoea* spp.	1.09 (0.17)	2	4.32 (0.19)	3
Horseweed	*Conyza canadensis* (L.) Cronq.	0.77 (0.20)	3	4.36 (0.19)	2
Annual grasses	—	0.18 (0.11)	4	—	—
Barnyardgrass	*Echinochloa crus-galli* (L.) Beauv.	0.09 (0.09)	5	3.73 (0.25)	6
Henbit	*Lamium amplexicaule* L.	0.09 (0.06)	5	4.14 (0.23)	5
Yellow nutsedge	*Cyperus esculentus* L.	0.09 (0.06)	5	3.55 (0.23)	8
Redvine	*Brunnichia ovata* (Walt.) Shinners	0.09 (0.09)	5	3.05 (0.22)	14
Goosegrass	*Eleusine indica* (L.) Gaertn.	0.09 (0.09)	5	2.59 (0.28)	21
Spotted spurge	*Chamaesyce maculata* (L.) Small	0.09 (0.09)	5	1.95 (0.25)	30
Smartweeds	*Polygonum* spp.	0.09 (0.09)	5	3.45 (0.27)	9
Top five problematic weeds of Mississippi					
Palmer amaranth	*Amaranthus palmeri* (S.) Wats.	2.50 (0.27)	1	4.70 (0.15)	1
Morningglories	*Ipomoea* spp.	1.30 (0.33)	2	3.60 (0.52)	8
Annual grasses	—	0.70 (0.33)	3	—	—
Horseweed	*Conyza canadensis* (L.) Cronq.	0.60 (0.34)	4	3.70 (0.50)	7
Italian ryegrass	*Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot	0.40 (0.27)	5	4.00 (0.42)	4
Hemp sesbania	*Sesbania herbacea* (P. Mill.) McVaugh	0.40 (0.22)	5	3.10 (0.38)	13
Top five problematic weeds of Louisiana					
Morningglories	*Ipomoea* spp.	1.35 (0.31)	1	4.19 (0.23)	2
Palmer amaranth	*Amaranthus palmeri* (S.) Wats.	0.76 (0.29)	2	3.94 (0.27)	3
Common waterhemp	*Amaranthus rudis* Sauer	0.53 (0.21)	3	3.00 (0.35)	11
Italian ryegrass	*Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot	0.47 (0.26)	4	3.75 (0.23)	5

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Table 3. Continued.

Common name	Scientific name	Problematic points (SEM)[a]	Problematic rank	Importance points (SEM)[b]	Importance rank
Annual grasses	—	0.41 (0.19)	5	—	—
Prickly sida	*Sida spinosa* L.	0.41 (0.21)	5	3.38 (0.29)	8
Browntop millet	*Brachiaria ramosa* (L.) Stapf	0.41 (0.23)	5	2.63 (0.36)	14
Top five problematic weeds of Tennessee					
Palmer amaranth	*Amaranthus palmeri* (S.) Wats.	2.91 (0.09)	1	5.00 (0.00)	1
Morningglories	*Ipomoea* spp.	1.09 (0.21)	2	4.30 (0.20)	4
Horseweed	*Conyza canadensis* (L.) Cronq.	1.00 (0.36)	3	4.64 (0.20)	2
Sicklepod	*Senna obtusifolia* (L.) H.S. Irwin & Barneby	0.27 (0.19)	4	3.18 (0.35)	6
Annual grasses	—	0.18 (0.12)	5	—	—
Goosegrass	*Eleusine indica* (L.) Gaertn.	0.18 (0.18)	5	3.09 (0.34)	7
Common cocklebur	*Xanthium strumarium* L.	0.18 (0.18)	5	2.36 (0.28)	13

[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 the three most problematic weeds by a consultant was assigned a value of 0. Standard error of mean (SEM) for each weed species is provided in parentheses.

[b] Importance points were calculated on the basis of 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 error of mean for each weed species is provided in parentheses.

[c] Species not specified by the consultants.

[d] Johnsongrass was ranked as first, second, third, and fourth most important weed of cotton in Louisiana, Mississippi, Tennessee, and Arkansas, respectively.

weed on roadsides adjacent to cotton fields in the Mississippi Delta (Bagavathiannan and Norsworthy, unpublished data).

Differences in environmental conditions, topography, cropping systems, and general agronomic practices influence the prevalence of weed species that are most adaptable to local conditions (Cardina et al. 2002). Hence, the top five most problematic weeds are also presented by state (Table 3). Palmer amaranth, morningglories, and horseweed were first, second, and third most problematic weeds in Arkansas and Tennessee. Mississippi cotton consultants ranked the first two problematic weeds similarly but replaced horseweed with annual grasses as their third most problematic weed. As described earlier, Palmer amaranth recently (in 2010) evolved resistance to glyphosate in Louisiana but is not as widespread as in Arkansas, Mississippi, and Tennessee (Nichols et al. 2009). Accordingly in Louisiana, morningglories were the most problematic weed, followed by Palmer amaranth and common waterhemp. All of the top problematic weed species are either resistant or tolerant to glyphosate, suggesting that continuous use of glyphosate in cotton has had a profound effect on the weed flora.

Glyphosate-Resistant Palmer Amaranth Management. Because of the lower prevalence of GR Palmer amaranth in Louisiana, Palmer amaranth was considered less problematic and important by the cotton consultants of Louisiana, which corresponded to differences in GR Palmer amaranth management practices in Louisiana compared with Arkansas, Mississippi, and Tennessee (collectively referred to as remaining midsouthern United States). Consequently, data regarding GR Palmer amaranth management questions are presented by Louisiana and the remaining midsouthern United States (Table 4).

Seventy-six percent of Louisiana cotton consultants compared with 90% of cotton consultants from the remaining midsouthern United States had a high level of concern about GR Palmer amaranth (Table 4). Only 65% of consultants from Louisiana compared with 98% from the remaining midsouthern United States suspected the presence of GR

Table 4. Spread and management of glyphosate-resistant (GR) Palmer amaranth in cotton fields of Louisiana (LA) and remaining midsouthern United States. (Arkansas [AR] + Mississippi [MS] + Tennessee [TN]).

GR Palmer amaranth management questions	LA ($n = 17$)	Remaining midsouthern United States ($n = 43$)
Concern about GR Palmer amaranth (% of total consultants)		
None	0	0
Slight	0	0
Moderate	24	10
High	76	90
Do you suspect GR Palmer amaranth on the farms? (% of consultants saying yes)	65	98
Area under GR Palmer amaranth (% of total scouted hectares)	13	75
Has tillage increased because of GR palmer amaranth? (% of consultants saying yes)	18	65
Area cultivated solely to control GR Palmer amaranth (% of total scouted hectares)	0	20
Are growers hand-weeding to remove Palmer amaranth? (% of consultants saying yes)	29	95
Area hand-weeded for Palmer amaranth control (% of total scouted hectares)	2.5	49
Area under hand-weeding (% of total scouted hectares)		
None	97	51
Only once	2.5	27
Only twice	0.06	15
Only thrice	0	6
≥ Four times	0	1
Average cost to hand-weed Palmer amaranth		
Average ($\$$ ha^{-1}) with min to max range	53 (12 to 74)	50 (12 to 124)
Maximum ($\$$ ha^{-1}) with min to max range	62 (12 to 99)	125 (12 to 371)

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Palmer amaranth in the scouted cotton. Percentage of total scouted area with suspected GR Palmer amaranth in Louisiana was 13% and in the remaining midsouthern United States was 75%, corresponding to 15,522 of a total of 119,400 planted cotton hectares in Louisiana and 548,000 of 730,700 planted cotton hectares in the remaining three states in 2011 (USDA-NASS 2012). Nichols et al. (2009) reported that Palmer amaranth collectively infested 124,050 cotton hectares in Arkansas, Mississippi, and Tennessee. Our current survey estimates that in the 2-yr period from 2009 to 2011, Palmer amaranth spread to an additional 400,000 cotton hectares in these three states. These numbers are expected to increase if proper and timely resistance management practices are not included in weed management programs.

When asked if tillage has increased because of GR Palmer amaranth, 18% of Louisiana consultants and 65% of the remaining midsouthern U.S. consultants responded that tillage had increased (Table 4). None of the scouted area in Louisiana compared with 20% of the scouted area in the remaining three states was cultivated solely to control GR Palmer amaranth. Because of the extensive area under no-tillage production systems (Table 2), area cultivated solely to control GR Palmer amaranth was only 6% in Tennessee compared with 36% in Arkansas and 19% in Mississippi (data not shown).

Numerous proactive midsouthern growers have relented to returning to manual hand-weeding GR weeds, including Palmer amaranth, to prevent its soil seedbank upsurge. When asked if their scouted fields are being hand-weeded for Palmer amaranth, an overwhelming number of cotton consultants (95%) from Arkansas, Mississippi, and Tennessee responded "yes" (Table 4). Twenty-nine percent of Louisiana consultants also reported that their growers are practicing hand-weeding to control Palmer amaranth. Of the total scouted cotton hectarage reported, 2.5% in Louisiana and 49% in the remaining midsouthern United States was hand-weeded at least once to control Palmer amaranth.

There was little difference in hand-weeded area between cotton (2.5% of total scouted) and soybean (3.5% of total scouted) in Louisiana, but Palmer amaranth hand-weeding in the remaining midsouthern United States was 49% of total scouted cotton compared with 15% of total scouted soybean (Table 4) (Riar et al. 2013). Reasons for greater area under hand-weeding in cotton compared with soybean is likely due to fewer herbicides to control Palmer amaranth POST over-the-top control options in RR cotton (Norsworthy et al. 2008), a slower-growing, less-competitive crop compared with soybean (Bryson et al. 2003), and less rotation of cotton with other crops compared with soybean (Shaw et al. 2009).

Most of the scouted hand-weeded area in Louisiana was hand-weeded once, but in the remaining midsouthern United States collectively 27, 15, 6, and 1% of the reported scouted hectares were hand-weeded one, two, three, and greater than or equal to four times, respectively (Table 4). The average cost of Palmer amaranth hand-weeding varied from 12 to $74 ha^{-1} in Louisiana and 12 to $124 ha^{-1} in the remaining midsouthern United States. Some consultants in Arkansas reported that some growers spent $371 ha^{-1} to hand-remove Palmer amaranth from cotton. The cost of hand-weeding reported here is comparable with the hand-weeding cost reported by others (Sosnoskie and Culpepper 2012; Steckel 2011).

As the need for Palmer amaranth hand-removal has increased dramatically over the past few years, so too has the difficulty in finding available labor and the difficulty in removing plants before seed set (Norsworthy et al. 2012). Of the five criteria listed in the survey questionnaire, three most often used by consultants to decide whether to hand-remove Palmer amaranth from cotton were (1) availability of labor, (2) size of weed, and (3) removal before weed seed production.

Weed Management Research Priorities. All cotton consultants were asked to list two research priorities that can improve weed management in cotton, and in response, an overwhelming number of cotton consultants (50%) requested research related to residual herbicides, specifically their requirements for incorporation, length of time a herbicide could lie on the soil surface before incorporation, length of expected weed control, comparison of fall- and spring-applied residual herbicides for the control GR weed species, timing of residual herbicides for GR Palmer amaranth control based on days after planting, and burndown residual herbicides with crop planting flexibility (Table 5). As noted in this survey as well as others (Prince et al. 2012b), cotton growers throughout the midsouthern United States have returned to the judicious use of residual herbicides in response to GR weeds, especially GR Palmer amaranth.

Twenty-five percent of consultants requested more research on POST herbicides, specifically research focusing on over-the-top control options for ALS-resistant and GR Palmer amaranth, improved postdirected herbicide options using all existing chemistries, importance of herbicide application timing, improvements in adjuvant selection to increase herbicide uptake, and ways to prevent off-target movement of 2,4-D and dicamba to adjacent crops (Table 5).

The importance for disseminating research findings to the end user, that being the consultant or grower, cannot be overstated, and to that end cotton consultants (13%) expressed the need for more training materials (Table 5). In particular, they wanted more training or training material related to spray application and ways to improve spray coverage, a greater number of research summaries and recommendations placed on the internet, ways to optimize the effectiveness of glufosinate in LL cotton, and workshops or training modules on weed identification.

Additionally, consultants (23%) requested more herbicide-related research on whether herbicide injury causes yield loss or delays in cotton maturity; programs for controlling GR Palmer amaranth in the absence of fomesafen because of fear of resistance; reduced rate recommendations for PRE herbicides and tank mixtures; and weed control along right-of-ways, turn rows, and ditch banks (Table 5). The recommendation for research on reduced rates of herbicides is very alarming, as this practice can lead to the rapid evolution of herbicide resistance (Busi et al. 2012; Neve and Powles 2005; Norsworthy et al. 2012). Consequently, there is an urgent need for continued efforts aimed at educating

Table 5. Topical summary of future research priorities for weed scientists as mentioned by cotton consultants of the midsouthern United States (Arkansas, Louisiana, Mississippi, and Tennessee, collectively).

Research and training priorities	Specific research interests	Midsouthern cotton consultants ($n = 60$), % of total
Residual herbicides	Effective residual herbicides that don't injure cotton	50
	Application techniques to improve consistency of weed control with residual herbicides	
	Length of expected weed control	
	Comparison of fall- and spring-applied residual herbicides for glyphosate-resistant (GR) and -tolerant weed species	
	Timing of residual herbicides based on days after planting	
	Burndown residual herbicides with crop planting flexibility	
POST herbicides	Over-the-top control options for acetolactate synthase (ALS)-inhibiting and GR Palmer amaranth	25
	Data to validate importance of herbicide timing	
	Improvements in adjuvant selection to increase herbicide uptake	
	Prevention of off-target movement of auxinic herbicides to adjacent susceptible crops	
Training materials	Methods to improve spray application and coverage	13
	Best management practices specific to glufosinate-resistant cotton	
	Techniques for ground application	
	Resistance management programs for GR Palmer amaranth	
	Weed identification programs	
	Availability of training material, research summaries, and recommendations on internet	
Other herbicide-related research priorites	New herbicide combinations	23
	Relation of herbicide injury to cotton yield loss and delay in maturity	
	Herbicide programs not containing fomesafen to control GR Palmer amaranth	
	Reduced rate recommendations for PRE herbicides and mixtures	
	Options to control volunteer GR crops	
	Weed control along right-of-ways, turn rows, and ditch banks	
New herbicide-resistant crop technologies	Herbicide-resistant crop that can be sprayed with a single herbicide	13
	Research and information on the new herbicide-resistant traits that will be commercialized soon	
	Development of 4-hydroxyphenylpyruvate dioxygenase (HPPD)-resistant cotton	
Soil seedbank	Reduction in the soil seedbank following rotation with corn	4
	Research that documents the importance and impact of soil seedbank on resistance management	
Tillage	Effect of breaking plow on Palmer amaranth emergence and control	4
	Integration of tillage into current weed control programs	

growers and consultants regarding best management practices to mitigate the risks of herbicide-resistant weeds.

Cotton consultants (13%) requested more research on development and testing of a new herbicide-resistant technology that can be sprayed with a single herbicide like glyphosate and development of 4-hydroxyphenylpyruvate dioxygenase (HPPD)-resistant cotton (Table 5). Companies today have technologies with stacked genes for resistance to one or more herbicides such as glyphosate, glufosinate, auxin herbicides (2,4-D and dicamba), and HPPD-inhibiting herbicides (isoxaflutole and mesotrione). Pending regulatory approval, major herbicide-resistant cotton technologies coming to market in the near future will include Bollgard II® RR® Xtend with LibertyLink (resistant to glyphosate, glufosinate, and dicamba; Monsanto, BASF, and Bayer CropSciences) and Enlist™ Weed Control System (resistant to glyphosate, glufosinate, and 2,4-D; Dow AgroSciences). Other herbicide resistance technologies that will become available later in soybean and cotton are Balance™ GT (resistant to glyphosate and isoxaflutole; Bayer CropScience and MS Technologies) and MGI herbicide system (resistant to mesotrione, glufosinate, and isoxaflutole; Syngenta and Bayer CropScience).

Recently, there has been a call for greater emphasis on reducing the soil seedbank as a means to manage herbicide-resistant weed species (Neve et al. 2011; Norsworthy et al. 2012). Most of the consultants requested more research related to herbicides and herbicide-resistant technologies, but few (4%) requested research on nonchemical strategies to minimize seed return to the seedbank (Table 5). The need for more research on tillage practices, specifically on the effect of breaking plow or deep tillage on Palmer amaranth emergence and control and additional research related to integration of tillage into current weed control programs, was mentioned by only 4% of consultants. The benchmark survey conducted in 2010 (Prince et al. 2012b) and our survey of soybean consultants in 2011 (Riar et al. 2013) reported an increase in tillage corresponding to evolution of GR weed species, but consultants do not seem to be too interested about more research on tillage and other cultural practices.

Obstacles to Grower Adoption of New Herbicide-Resistant Technologies. When asked to list one or more grower obstacles to adoption of new herbicide-resistant technologies that may be registered over the next 5 yr in cotton, consultants responded similarly for both auxinic-resistant traits (2,4-D- and dicamba-resistant cotton) but responded differently for HPPD-resistant cotton; thus data for concerns related to adoption of 2,4-D- and dicamba-resistant cotton were pooled (data not shown). The most frequently noted concern for auxin-resistant cotton was off-target herbicide movement to neighboring fields with susceptible crops (68% consultants) and sprayer cleanout (15% consultants). Only 19 and 2% of

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consultants had concern regarding off-target movement and sprayer cleanout, respectively, of HPPD-inhibiting herbicides. Added cost and a likely yield drag were perceived to accompany both of these technologies.

Other concerns for the adoption of these new technologies included: fear of evolution of resistance to these herbicides, rotation restrictions, level of broad-spectrum weed control with the auxin herbicides, and most likely a lack of added grass control. Interestingly, 32% of consultants could not think of any obstacles associated with the adoption of HPPD-resistant cotton compared with only 6% that perceived there would be no hindrance to the adoption of auxinic-resistant cotton.

In summary, most of the cotton planted in the midsouthern United States in 2011 was resistant to glyphosate. As expected, there is continuous weed species shift toward glyphosate-resistant and -tolerant weed species, but GR Palmer amaranth has replaced GR horseweed as the most problematic weed of cotton in this region. The sole use of glyphosate in herbicide programs has decreased tremendously and consultants are optimistic about new technologies addressing or solving their current weed management problems. Use of residual herbicides and tillage in weed management programs has increased; however, there is still a need for greater grower and consultant education regarding resistance management practices in midsouthern U.S. cotton.

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Literature Cited

Barnes, L. D. and R. W. Whitmore. 1990. The use of Prowl herbicide as a preemergence treatment in an irrigated reduced tillage cotton production system. Proc. Beltwide Cotton Conf. 14:349–350.

Bourland, F. M., A. B. Beach, J. M. Hornbeck, and A. J. Hood. 2009. Arkansas Cotton Variety Test 2008. University of Arkansas Agricultural Experiment Station Research Series 567:20.

Bryson, C. T., K. N. Reddy, and W. T. Molin. 2003. Purple nutsedge (*Cyperus rotundus*) population dynamics in narrow row transgenic cotton (*Gossypium hirsutum*) and soybean (*Glycine max*) rotation. Weed Technol. 17:805–810.

Busi, R., P. Neve, and S. Powles. 2013. Evolved polygenic herbicide resistance in Lolium rigidum by low-dose herbicide selection within standing genetic variation. Evol. Appl. 6:231–242.

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

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. 27:263–270.

Dickson, J. W, R. C. Scott, N. R. Burgos, R. A. Salas, and K. L. Smith. 2011. Confirmation of glyphosate-resistant Italian ryegrass (Lolium perenne ssp. multiflorum) in Arkansas. Weed Technol. 25:674–679.

Givens, W. A., D. R. Shaw, G. R. Kruger, W. G. Johnson, S. C. Weller, B. G. Young, R. G. Wilson, M.D.K. Owen, and D. Jordan. 2009. Survey of tillage trends following the adoption of glyphosate-resistant crops. Weed Technol. 23:150–155.

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.

Hammond, E. 2010. Genetically engineered backslide: The impact of glyphosate-resistant Palmer pigweed on agriculture in the United States. TWN Biotechnology and BioSafety Series 12. Pp. 1–22.

Heap, I. 2013. The International Survey of Herbicide Resistant Weeds. http://www.wssa.net. Accessed April 8, 2013.

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.

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.

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., J. K. Norsworthy, K. L. Smith, and I. Zelaya. 2011. Modeling glyphosate resistance management strategies for Palmer amaranth in cotton. Weed Technol. 25:335–343.

Neve, P. and S. Powles. 2005. Recurrent selection with reduced herbicide rates results in the rapid evolution of herbicide resistance in *Lolium rigidum*. Theor. Appl. Genet. 110:1154–1166.

Nichols, R. L., J. Bond, A. S. Culpepper, D. Dodds, V. Nandula, C. L. Main, M. W. Marshall, and A.C. York. 2009. Glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*) spreads in the Southern United States. Resist. Pest Manag. Newsl. 18:8–10.

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. 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., 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) 60:31–62.

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. 2012a. Benchmark Study: I. Introduction, weed population, and management trends from the Benchmark Survey 2010. Weed Technol. 26:525–530.

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: IV. Survey of grower practices for managing glyphosate-resistant weed populations. Weed Technol. 26:543–548.

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

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, L. E. Steckel, D. O. Stephenson, IV, T. W. Eubank, and R. C. Scott. 2013. Assessment of weed management practices and problem weeds in the midsouthern United States soybean: a consultant's perspective. Weed Technol. 27:788–797.

Rowland, M. W., D. S. Murray, and L. M. Verhalen. 1999. Full-season Palmer amaranth (*Amaranthus palmeri*) interference with cotton (*Gossypium hirsutum*).Weed Sci. 47:305–309.

Scott, R. C., J. W. Boyd, K. L. Smith, G. Selden, and J. K. Norsworthy. 2012. Recommended Chemicals for Weed and Brush Control. Page 36, University of Arkansas Division of Agriculture, Cooperative Extension Service, Miscellaneous Publication 44.

Shaw, D. R. and J. C. Arnold. 2002. Weed control from herbicide combinations with glyphosate. Weed Technol. 16:1–6.

Shaw, D. R., W. A. Givens, L. A. Farno, P. D. Gerard, D. Jordan, W. G. Johnson, S. C. Weller, B. G. Young, R. G. Wilson, and M.D.K. Owen. 2009. Using a grower survey to assess the benefits and challenges of glyphosate-resistant cropping systems for weed management in U.S. corn, cotton, and soybean. Weed Technol. 23:134–149.

Sosnoskie, L. M. and S. Culpepper. 2012. Changes in cotton weed management practices in Georgia following the development of glyphosate-resistant Palmer amaranth. Proc. 2012 Beltwide Cotton Conference. http://www.gaweed.com/slides/beltwide-sosnoskiesurvey/beltwide-sosnoskiesurvey.pdf. Accessed April 12, 2013.

Steckel, L. E. 2011. Glyphosate-resistant weeds: lessons learned in Tennessee. Proc. CPM shortcourse and MCPR Trade Show. http://www.extension.umn.edu/AgProfessionals/components/CPM/2011/Steckel.pdf. Accessed April 12, 2013.

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.

[USDA-NASS] United States Department of Agriculture, National Agricultural Statistics Service. 2012. Acreage: http://www.usda.gov/nass/PUBS/TODAYRPT/acrg0612.pdf. Accessed April 5, 2013.

Vebree, D. 2013. Effect of maturity and row-spacing on yield of irrigated soybeans. *In* Proceedings of the 2013 Beltwide Cotton Conference. Cordova, TN: National Cotton Council of America. In press.

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

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