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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:
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A Midsouthern Consultant's Survey on Weed Management Practices in Soybean

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Abstract

Soybean consultants from Arkansas, Louisiana, southeast Missouri, Mississippi, and Tennessee were surveyed in 2016 to assess weed management practices and the prevalence of herbicide-resistant weeds in midsouthern U.S. soybean production. The consultants surveyed represented 13%, 28%, 8%, 16%, and 5% of the total soybean area planted in Arkansas, Louisiana, southeast Missouri, Mississippi, and Tennessee, respectively. Of the total scouted area, 78% of the consultants said their growers planted glyphosate-resistant soybean in 2016, with 18% planting glufosinate-resistant (LibertyLink®), primarily due to familiarity with and cost of the technology. Although 94% of the consultants determined that glufosinate was most effective on killing Palmer amaranth, the primary concern associated with controlling herbicide-resistant weeds was the associated cost, followed by return profit and time constraints. Palmer amaranth, morningglory species, horseweed, barnyardgrass, and Italian ryegrass were the five most problematic weeds in soybean across the five states. Palmer amaranth was the most problematic and important weed in each state individually. The increased concern (77% of consultants) with this species was attributed to the rising concern with and occurrence of protoporphyrinogen oxidase–resistant Palmer amaranth. Consultants were of the opinion that more research was needed on cover crops and the new traited technologies in order to improve weed management in soybean.

Introduction

Crop production and weed management tactics change over time. Glyphosate-resistant (Roundup Ready® [RR], Monsanto, St. Louis, MO) soybean was readily adopted due to the ease of use of the technology. Today, RR soybean is still the primary soybean cultivar planted in the United States (USDA National Agricultural Statistics Service [USDA-NASS] 2016). However, the overuse of glyphosate has led to an increase in glyphosate-resistant (GR) weeds. In 2013, glyphosate and glufosinate were reported to be sprayed alone to 9% and 13% of the reported RR and glufosinate-resistant (LibertyLink® [LL], Bayer CropScience, Monheim am Rhein, Germany) soybean hectares, respectively, in several midsouthern states (Riar et al. 2013b).

The overuse of glyphosate in RR soybean allowed for weeds to evolve resistance to this mode of action (MOA) and caused a shift toward weeds that escape glyphosate control due to late or continual germination (Reddy and Norsworthy 2010). Emergence of annual grasses and pigweeds (*Amaranthus* spp.) in several flushes throughout the season allow these weeds to escape early-season glyphosate applications in the absence of residual herbicides (Tharp and Kells 2002). The prevalence of and concern surrounding GR species like Palmer amaranth has led to an increase in soil-applied residual herbicides, primarily protoporphyrinogen oxidase (PPO)-inhibiting herbicides (Owen and Zelaya 2005).

Adoption of best management practices (BMPs) for mitigating the risk of herbicide-resistant weeds evolving is imperative for the sustainability of cropping systems (Green 2007). As a result, Norsworthy et al. (2012) recommended 12 BMPs that can help reduce herbicide-resistant weeds. The adoption of these BMPs can overcome real and perceived obstacles that growers face, including costs associated with managing herbicide-resistant weeds, which does not seem to deter growers. Although no new herbicide MOAs are foreseen in the near future, growers believe that a new herbicide will eventually be developed to mitigate herbicide resistance (Foresman and Glasgow 2008).

In the midsouthern United States, growers rely on crop consultants to scout their fields and provide appropriate recommendations for both crop and weed management. Thus, they have

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information about problematic weed species in their fields and what management approach is needed. Therefore, a soybean weed management survey was constructed for soybean consultants in the midsouthern United States to determine the consultants' perspective on the area under specific herbicide-resistant traits, general soybean production practices, general weed management practices, the importance and adoption of various herbicide-resistant BMPs, problematic weed species, and the perceived area infested with PPO-resistant Palmer amaranth.

Materials and Methods

In fall 2016, a survey questionnaire was made available online (https://www.surveymonkey.com/r/surveysoybean) to crop consultants from Arkansas, Louisiana, Mississippi, southeast Missouri, and Tennessee. It is unknown how many soybean consultants received the website link, since the survey was available online and broadcast on statewide or regional consultant list servers. The survey questionnaire was divided into four main sections: (1) general weed management, (2) herbicide-resistance management, (3) problematic weed species, and (4) PPO-resistant Palmer amaranth.

The first section focused on general weed management. The survey questions are listed in Appendix 1. In the second section, consultants were provided with a list of obstacles that growers face with adopting resistance management strategies 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 (this scale was similar to that in Riar et al. 2013b). Additionally, consultants were asked which of those obstacles they believe would increase or decrease over the next couple of years and to describe why. In the third section, consultants were provided with a list of 38 potential weeds in their area and were asked to rate the importance of each on a scale of 1 to 5. They were further asked to list their three most problematic weeds. The fourth section was related to the control and spread of PPO-resistant Palmer amaranth. In addition, consultants were asked to provide recommendations being given to growers who have PPO-resistant Palmer amaranth in their fields. Finally, consultants were asked to identify two areas of research that would help improve weed management in soybean.

Results and Discussion

Soybean Area Scouted

A total of 25, 24, 9, 11, and 7 registered consultants responded to the survey ($n = 76$) from Arkansas, Louisiana, Mississippi, southeast Missouri (four counties), and Tennessee, respectively. These consultants represent 13% (170,587 ha), 28% (142,105 ha), 8% (39,798 ha), 16% (38,680 ha), and 5% (33,502 ha) of the total soybean hectares planted in Arkansas (1,275,304 ha), Louisiana (506,073 ha), Mississippi (829,996 ha), southeast Missouri (497,479 ha), and Tennessee (708,502 ha), respectively, in 2016 (USDA-NASS 2016).

General Weed Management

Out of the total area scouted by the consultants surveyed, 74%, 92%, 42%, 76%, and 69% of Arkansas, Louisiana, Mississippi, Missouri, and Tennessee, respectively, was planted to RR soybean in 2016. The collective area planted under this technology was 78% across all states, while the remaining acreage was planted with 18% LL, 3% RR Xtend® (Monsanto) glyphosate- and dicamba-tolerant, and 1% conventional soybean varieties. Of the total area surveyed across this geography, 86% was treated with a PRE herbicide and 98% with a POST herbicide. The three most commonly used active ingredients applied PRE were flumioxazin, metribuzin, and metolachlor, and POST applications were glyphosate, glufosinate, and fomesafen. Overall 51% and 47% of the area reported was sprayed with more than three and two sites of action (SOAs), respectively, in crop. However, it is unclear whether growers fully understand SOAs or can properly identify active ingredients in various SOAs (Norsworthy et al. 2017b).

As herbicide resistance is a continual problem in soybean, new traits are expected to become available to help combat resistance issues. The traits expected to be planted in 2017 include RR, LL, Xtend®, and conventional. In addition, Enlist™, glyphosate, glufosinate, and 2,4-D choline tolerant (Dow AgroSciences, Indianapolis, IN), was included in case the trait was approved for global import before planting; however, import approvals were not obtained before the 2017 growing season. The addition of Xtend® and Enlist™ technologies allow for additional SOAs to be used without damaging the crop. In 2017, consultants expected their total soybean acreage to increase by 7%, 7%, 5%, 2%, and 10% in Arkansas, Louisiana, Mississippi, southeast Missouri, and Tennessee, respectively, from 2016. Consultants anticipated that, in 2017, the majority of their scouted fields would be planted with RR, LL, or Xtend® soybean, averaging 52%, 20%, and 35%, respectively.

Limited herbicide options remain for control of some weed species (e.g., Palmer amaranth) in soybean. Glufosinate-resistant soybean has been heavily relied upon in recent years in geographies where glyphosate and PPO resistance are most prevalent (JKN, personal observation). With what herbicides remain, studies in Arkansas have shown that on PPO-resistant populations, glufosinate has shown to provide a high level of control (99%), whereas a single application of dicamba (80%) or glyphosate (10%) provided marginal or little mortality (Norsworthy et al. 2017a; Schwartz-Lazaro et al. 2017).

The survey further asked consultants why they believe their growers would choose a specific trait in 2017 (Table 1). RR soybean was primarily chosen based on two factors: superior yields and economics (other than seed cost). The choice to plant

Table 1. Consultants' perspectives on the likely reason why a specific soybean herbicide-resistant trait will be grown in 2017.[a,b]

	RR	LL	RR Xtend®	Conventional
	——— % scouted area ———			
Low seed cost	14	2	0	37
Economics (other than seed cost)	25	2	0	12
Fear of drift from neighbor	7	0	31	0
Superior yields	26	0	6	0
Ability to control resistant weeds	7	83	44	0
Complexity of the application requirements on new technologies	7	2	0	0
Other (please specify)[c]	15	13	19	51

[a]Abbreviations: LL, LibertyLink®; RR, Roundup Ready®.
[b]Data pooled across states surveyed.
[c]"Other" explanations provided within the text.

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LL soybean was often because glufosinate enables resistant weeds to be controlled. RR Xtend® was perceived by the respondents to be chosen because of the ability to control herbicide-resistant weed species and out of fear of drift from neighbors. Reasons given for why conventional soybeans were planted included low seed cost (most common response) and premium received for non-GMO grain. A large percentage of consultants provided "other" as a reasoning for choosing to plant a soybean variety (Table 1). The answers varied by technology. Consultants believed that some growers were not willing to switch from RR due to their current comfort with this system and the lower seed costs associated with this technology. Others reported that growers are reluctant to shift from RR soybean technology to non-GR alternatives, because they perceive these alternatives as more costly and less time efficient (Green and Owen 2011). Consultants believed some growers would plant RR and LL soybean because of the unavailability of Xtend® soybean seed.

Herbicide-Resistance Management

Consultants were asked to rank seven important perceived obstacles in adopting herbicide resistance BMPs. Overall, they ranked cost as the largest obstacle and availability of equipment, such as sprayers, as the least important obstacle (Table 2). At the state level, cost was still the largest obstacle, except for Mississippi. Mississippi's largest obstacle was considered to be time constraints, which was ranked as the third largest obstacle overall. Louisiana, Missouri, and Mississippi all ranked the availability of equipment as the smallest obstacle, whereas Arkansas and Tennessee ranked complacency as the least important obstacle in adopting herbicide-resistance BMPs (Table 2).

Previous surveys have documented appropriate timing of herbicide applications as the most important herbicide-resistance BMP (Prince et al. 2012; Riar et al. 2013a). However, in this survey, appropriate herbicide application timings were only adopted on 42% of the total areas scouted (Table 3). Starting with weed-free fields (73%) and using multiple effective SOAs (64%) were the two most important BMPs adopted by growers in the midsouthern United States. Starting clean has been a widely recommended herbicide-resistance BMP (Norsworthy et al. 2012) and was ranked among the top five weed management practices by U.S. cotton (*Gossypium hirsutum* L.), soybean, and corn (*Zea mays* L.) growers averaged across 22 states (Prince et al. 2012). Planting into weed-free fields has not changed since a similar survey was conducted in 2011 of scouted midsouthern soybean hectares (Riar et al. 2013b). The lack of an increase in use of multiple effective SOAs compared with the earlier survey of consultants in this region is concerning. Overlay of residual herbicides of multiple SOAs every 2 to 3 wk until crop canopy formation is highly recommended to delay the evolution of and reduce selection pressure on herbicide-resistant weeds (Norsworthy et al. 2012).

Table 2. Ranking of limitations to adoption of herbicide resistance best management practices (HR-BMPs).[a]

Limitation to adopting HR-BMPs	Overall	AR	LA	MO	MS	TN
Cost	1	1	1	1	4	1
Profit	2	5	2	3	2	3
Time constraints	3	2	3	4	1	2
Weather	4	4	4	2	3	4
Complacency	5	7	6	5	6	7
Lack of labor or trained employees	6	3	5	6	5	5
Availability of equipment	7	6	7	7	7	6

[a]Importance ranking was based on the number of importance points. The rating scale was 1 = greatest importance to 7 = least important.

Table 3. Farmer adoption of herbicide-resistance best management practices (HR-BMPs) as perceived by midsouthern U.S. soybean consultants.

HR-BMPs	Area adopted
	% of scouted area
Start clean	73
Multiple effective herbicide modes of action	64
Crop rotation	52
Full labeled herbicide rates	43
Proper herbicide timing	42
Tillage (disk, cultivation, or deep tillage)	10
Cultural practices	8
Soil seedbank management	5
Trait rotation	3
Sanitation (cleaning equipment, planting weed-free seed)	2

Consultants were asked which of the 10 adopted herbicide-resistance BMPs (Table 3) would increase or decrease in adoption over the next 5 yr. The top three BMPs that consultants believed would increase were using multiple effective SOAs (42%), proper herbicide application timing (13%), and the use of cultural practices (12%). Conversely, consultants believed that equipment sanitation (18%), tillage (17%), and trait rotation (17%) would decrease over the next 5 yr. Previous research has shown that the cleaning and sanitation of tillage and harvest equipment is a primary means of minimizing the likelihood of weed introductions and spread throughout a farm and neighboring farms (Norsworthy et al. 2012). Although tillage has the potential to suppress the evolution of herbicide-resistant weeds, growers often fail to acknowledge the importance of tillage and adopt this practice (Frisvold et al. 2009). Finally, rotation of crops with herbicide-resistant traits, such as glyphosate- or glufosinate-resistant soybean, is important, but rotation of crops with the same herbicide-resistant trait, for example, GR cotton, soybean, and corn, has minimal advantage because of similar levels of selection pressure on evolution of herbicide-resistant weeds. Consultants believe that these three herbicide resistance BMPs will decline over the next 5 yr due to cost and unwillingness of the growers to alter their current effective practices. Furthermore, this assumes that effective chemical control options will remain available.

Problematic Weed Species

The overreliance on a single SOA, such as glyphosate, has led to shifts in the weed spectrum both below- and aboveground. The weed species shift has been shown to be due to geography,

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agronomic practices, environmental conditions, soil moisture, and effectively controlling the soil seedbank (Cardina et al. 2002; Schwartz et al. 2015). While annual management practices will readily alter the aboveground weed flora, the soil seedbank is typically slower to respond because of the inherent buffering capacity caused by seeds present from multiple seasons of seed rains (Schwartz et al. 2015). In this survey, Palmer amaranth, morningglory species, horseweed, barnyardgrass, and Italian ryegrass were the five most problematic weeds in soybean across the five states (Table 4).

Problematic weed species were further divided by individual state. Palmer amaranth was the most problematic weed in the Midsouth, regardless of state, mainly due to widespread herbicide resistance and the large number of plants that need to be controlled each year (Table 4). Palmer amaranth is considered the most prominent weed in soybean production in the midsouthern United States today and is currently resistant to six herbicide SOAs (Heap 2017; Norsworthy et al. 2014). This species has shown the ability to significantly reduce crop yield if not controlled. For example, a density of only 8 Palmer amaranth plants m^{-2} present at soybean emergence reduced grain yield by 78% (Bensch et al. 2003). Morningglory species were the second most problematic in Arkansas and Mississippi and the third most problematic in Missouri. Although these species are not currently resistant to any SOA, plants can be difficult to control with the currently available soybean herbicides (Webster 2013). In addition, seed from this annual vine can persist in soil for at least 39 yr, causing continual problems for farmers if not controlled early in the growing season (Toole and Brown 1946). The third most problematic weed across states was horseweed, which was the second most problematic weed in Tennessee and the third most problematic weed in Louisiana and Mississippi. Barnyardgrass, the fourth most problematic weed in the Midsouth, was the third most problematic weed in Arkansas and Tennessee. This species is currently resistant to seven SOAs, and in soybean, Vail and Oliver (1993) found a 10%, 25%, and 50% reduction of yield with respective barnyardgrass densities of 42, 110, and 250 plants m^{-1} of row. The fifth most problematic weed, Italian ryegrass, was considered the second most problematic weed in Louisiana, likely because of the increase of glyphosate resistance.

A similar weed survey conducted in the fall of 2011 (Riar et al. 2013b) included a comparable problematic weed survey. The top three weed species from Arkansas were the same in 2011. In Louisiana, the weed species remained the same, but the order changed, with the most problematic weeds in 2011 being morningglory, Palmer amaranth, and Italian ryegrass. The first two weed species in Mississippi remained the same; the third species in 2011 was Italian ryegrass. The top three weed species in Tennessee in 2011 were Palmer amaranth, morningglory, and horseweed. Barnyardgrass was not in the top five weed species previously.

Most weed species in the top five most problematic weeds are resistant or tolerant to at least one commonly used herbicide SOA. The evolution and spread of GR Palmer amaranth (Norsworthy et al. 2008), horseweed (Koger et al. 2004), and Italian ryegrass (Nandula et al. 2012), and the tolerance of morningglory, prickly sida (*Sida spinosa* L.), and hemp sesbania [*Sesbania herbacea* (P. Mill.) McVaugh] (Riar et al. 2011) to glyphosate are most likely the reasons for the dominance of these weed species. Barnyardgrass is the only weed in the five top-ranking species that is inherently susceptible to both glyphosate and glufosinate applications (Scott et al. 2017). Ecological traits of barnyardgrass such as prolonged emergence and high seed production allow the soil seedbank to be replenished each year. Most soybean fields in the Midsouth, especially in Arkansas, Louisiana, Missouri, and Mississippi, are rotated with rice, and barnyardgrass has evolved resistance to many herbicides used in rice production. These herbicides include propanil, quinclorac, clomazone, cyhalofop, and several acetolactate synthase–inhibiting herbicides (Heap 2017).

PPO-Resistant Palmer Amaranth

PPO-resistant Palmer amaranth was reported in Arkansas in 2011, in Tennessee in 2015, and in Illinois in 2016 (Heap 2017). The overreliance on one SOA can lead to a high selection rate for resistance, which has affected weed management strategies and effectiveness over the past decade (Hager et al. 2003; Riggins and Tranel 2012). The continual evolution of resistance to widely used and effective SOAs has led to increasing use of PPO-inhibiting herbicides for Palmer amaranth control (Schwartz-Lazaro et al. 2017). Overall, 79% of the scouted area has had a PPO inhibitor applied to it multiple times over the past 3 yr. Of the consultants surveyed, 77% perceived PPO-resistant Palmer amaranth to be of high concern, and 69% suspected that they have PPO-resistant Palmer amaranth on the fields they scout. This represents 39% (67,211 ha), 24% (34,674 ha), 45% (17,483 ha), 33% (17,702 ha), and 65% (13,750 ha) of the surveyed areas in Arkansas, Louisiana, Mississippi, southeast Missouri, and Tennessee, respectively. Interestingly, PPO-resistant Palmer amaranth has not been documented in Louisiana.

These results align with previous research that tested five PRE and four POST PPO-inhibiting herbicides in Arkansas. Complete control was not achieved at the 8X rate with any herbicide at the PRE application; for the POST application, complete control was not achieved until the 32X rate for all herbicides (Schwartz-Lazaro et al. 2017). Furthermore, Wuerffel et al. (2015) found that an Illinois PPO-resistant population had 38X, 3.2X, and 29X R/S ratios for fomesafen, sulfentrazone, and flumioxazin, respectively.

Due to this high concern with PPO-resistant Palmer amaranth, consultants are primarily advising their growers to switch to either LL or RR Xtend® soybean traits, to have no emerged weeds present at planting, and to use multiple effective SOAs. Additional suggestions include the use of cover crops, narrow rows, crop rotation, and timely herbicide applications. Although the majority of farms scouted have suspected PPO-resistant Palmer amaranth, consultants are split (55%: increase; 45%: decrease) on whether more tillage will be used to help combat this problem. This is interesting, because consultants previously (see earlier discussion of BMPs) thought that tillage would decrease in the coming years. In the Midsouth, PPO inhibitors have been extensively used over the past 8 to 10 yr to combat GR Palmer amaranth in various cropping systems, especially soybean (Owen and Zelaya 2005). Additional herbicide SOAs that are effective on a wide range of problem weed species are needed to enhance SOA diversity, which would lessen the risks of herbicide-resistance evolution (Norsworthy et al. 2012) and could improve Palmer amaranth control. Furthermore, despite the emergence of technologies that will increase the number of chemical weed control options in various crops, weed management programs that rely solely on a single herbicide are not sustainable (Meyer et al. 2015; Norsworthy et al. 2012).

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Table 4. Consultants ranking of weeds in midsouthern United States soybean (data from all states were pooled), with the top three most problematic weeds from each state.

Common name	Scientific name	Importance points (SE)[a]	Importance rank	Problematic points (SE)[b]	Problematic rank
Palmer amaranth	*Amaranthus palmeri* S. Wats.	4.78 (0.07)	1	2.48 (0.11)	1
Italian ryegrass	*Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot	4.12 (0.09)	2	0.28 (0.06)	5
Horseweed	*Conyza canadensis* (L.) Cronq.	4.11 (0.09)	3	0.55 (0.07)	3
Johnsongrass	*Sorghum halepense* (L.) Pers.	4.00 (0.12)	4	0.15 (0.04)	8
Morningglory species	*Ipomoea* spp.	3.94 (0.12)	5	0.62 (0.09)	2
Barnyardgrass	*Echinochloa crus-galli* (L.) Beauv.	3.82 (0.13)	6	0.45 (0.08)	4
Yellow nutsedge	*Cyperus esculentus* L.	3.70 (0.13)	7	0.18 (0.05)	7
Prickly sida	*Sida spinosa* L.	3.58 (0.11)	8	0.28 (0.06)	5
Tall waterhemp	*Amaranthus tuberculatus* (Moq.) Sauer	3.52 (0.11)	9	0.25 (0.03)	6
Broadleaf signalgrass	*Urochloa platphylla* (Nash.) R. D. Webster	3.38 (0.14)	10	0.08 (0.03)	11
Henbit	*Lamium amplexicaule* L.	3.34 (0.12)	11	0	0
Crabgrass species	*Digitaria* spp.	3.22 (0.12)	12	0.10 (0.03)	10
Red rice	*Oryza sativa* L.	3.17 (0.09)	13	0.13 (0.04)	9
Hemp sesbania	*Sesbania herbacea* (P. Mill.) McVaugh	3.06 (0.11)	14	0.03 (0.02)	14
Redvine	*Brunnichia ovata* (Walt.) Shinners	3.05 (0.11)	15	0.05 (0.04)	13
Smartweed species	*Polygonum* spp.	3.05 (0.11)	15	0	0
Cutleaf evening-primrose	*Oenothera laciniata* Hill	2.94 (0.13)	16	0	0
Giant ragweed	*Ambrosia trifida* L.	2.92 (0.13)	17	0	0
Sicklepod	*Senna obtusifolia* (L.) H. S. Irwin & Barneby	2.82 (0.14)	18	0.07 (0.04)	12
Goosegrass	*Eleusine indica* (L.) Gaertn.	2.78 (0.14)	19	0.02 (0.01)	15
Common ragweed	*Ambrosia artemisifolia* L.	2.75 (0.14)	20	0.03 (0.02)	14
Fall panicum	*Panicum dichotomiflorum* Michx.	2.65 (0.12)	21	0.02 (0.02)	15
Curly dock	*Rumex crispus* L.	2.60 (0.12)	22	0	0
Annual bluegrass	*Poa annua* L.	2.57 (0.09)	23	0	0
Velvetleaf	*Abutilon theophrasti* Medik.	2.50 (0.09)	24	0	0
Chickweed species	*Cerastium* spp., *Stellaria* spp.	2.45 (0.11)	25	0	0
Spotted spurge	*Chamaesyce maculata* (L.) Small	2.40 (0.11)	26	0	0
Bermudagrass	*Cynodon dactylon* (L.) Pers.	2.38 (0.13)	27	0.02 (0.01)	15
Eclipta	*Eclipta prostrata* (L.) L.	2.37 (0.13)	28	0	0
Hophornbeam copperleaf	*Acalypha ostryifolia* Riddell	2.36 (0.13)	29	0	0
Carolina geranium	*Geranium carolinianum* L.	2.34 (0.12)	30	0	0
Groundcherry species	*Physalis* spp.	2.30 (.012)	31	0.02 (0.02)	15
Common purslane	*Portulaca oleracea* L.	2.28 (0.09)	32	0	0
Spurred anoda	*Anoda cristata* (L.) Schlecht.	2.28 (0.09)	32	0	0
Browntop millet	*Urochloa ramosa* (L.) Nguyen	2.23 (0.11)	33	0.03 (0.02)	14

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Table 4. (*Continued*)

Common name	Scientific name	Importance points (SE)[a]	Importance rank	Problematic points (SE)[b]	Problematic rank
Common lambsquarters	*Chenopodium album* L.	2.18 (0.14)	34	0	0
Common cocklebur	*Xanthium strumarium* L.	2.17 (0.14)	35	0.03 (0.02)	14
Shepherd's-purse	*Capsella bursa-pastoris* (L.) Medik.	2.16 (0.14)	36	0	0
Top three problematic weeds in Arkansas					
Palmer amaranth	*Amaranthus palmeri* S. Wats.	4.95 (0.06)	1	2.89 (0.12)	1
Morningglory species	*Ipomoea* spp.	4.25 (0.12)	5	0.89 (0.09)	2
Barnyardgrass	*Echinochloa crus-galli* (L.) Beauv.	3.00 (0.13)	6	0.58 (0.07)	3
Top three problematic weeds in Louisiana					
Palmer amaranth	*Amaranthus palmeri* S. Wats.	4.75 (0.09)	1	2.16 (0.11)	1
Italian ryegrass	*Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot	2.25 (0.13)	2	0.68 (0.08)	2
Horseweed	*Conyza canadensis* (L.) Cronq.	2.05 (0.14)	3	0.58 (0.07)	3
Top three problematic weeds in Missouri					
Palmer amaranth	*Amaranthus palmeri* S. Wats.	4.15 (0.11)	1	2.00 (0.10)	1
Crabgrass species	*Digitaria* spp.	2.65 (0.14)	12	0.57 (0.07)	2
Morningglory species	*Ipomoea* spp.	1.75 (0.16)	5	0.43 (0.06)	3
Common cocklebur	*Xanthium strumarium* L.	1.55 (0.16)	35	0.43 (0.06)	3
Top three problematic weeds in Mississippi					
Palmer amaranth	*Amaranthus palmeri* S. Wats.	4.18 (0.10)	1	2.89 (0.12)	1
Morningglory species	*Ipomoea* spp.	2.75 (0.15)	5	0.78 (0.08)	2
Horseweed	*Conyza canadensis* (L.) Cronq.	1.23 (0.16)	3	0.67 (0.07)	3
Top three problematic weeds in Tennessee					
Palmer amaranth	*Amaranthus palmeri* S. Wats.	4.65 (0.11)	1	2.12 (0.11)	1
Horseweed	*Conyza canadensis* (L.) Cronq.	3.28 (0.14)	5	1.50 (0.10)	2
Barnyardgrass	*Echinochloa crus-galli* (L.) Beauv.	2.04 (0.13)	6	0.50 (0.07)	3
Prickly sida	*Sida spinosa* L.	2.04 (0.13)	8	0.50 (0.07)	3

[a]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 for each weed species provided in parentheses.
[b]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 for each weed species provided in parentheses.

Suggested Research Priorities

An effort was made to try and summarize areas of research deemed to be of greatest importance by the consultants responding to the survey. Not all consultants suggested research; hence, there were 85 responses (only 2 responses were allowed per consultant). The two areas that were most frequently listed were cover crops (13 responses) and the new traited technologies available in soybean (9 responses). In regard to cover crops, consultants wanted to see research defining the necessary seeding rate to optimize weed control for an assortment of cover crops, comparison of the efficacy and length of residual weed control with herbicides used in combination with cover crops, the economics of cover crops in soybean weed control systems, herbicide options for terminating cover crops, and integration of cover crops into new herbicide-resistance traits. Consultants asked for: research on comparison of new herbicide-resistance technologies in regard to identifying strengths and weaknesses of each system; a side-by-side comparison of traits with emphasis on ease of implementation, weed control expectations, and returns to the soil seedbank; and identification of strategies for preservation of the new traits (i.e., lower risk for resistance), such as practical ways to integrate tillage and other nonchemical options into these systems. There were five responses requesting research on off-target movement of herbicides through comparison of the new auxin traits back to current standards like glufosinate and glyphosate. In addition, responses included evaluating efficacy as a function of nozzle selection for various herbicides and weed

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species, the use of hooded sprayers to reduce drift, and herbicide options in buffers and along turnrows where weed control is most challenging. Four responses called for greater emphasis on herbicide discovery, specifically finding a new MOA. While we acknowledge the need for a new MOA, especially in light of increasing resistance to the MOAs that are currently available, university weed scientists do not have the needed resources for herbicide discovery. Two consultants noted the need for improved application techniques that maximize herbicide performance, while two others suggested research comparing fall versus spring burndown options in order to determine which would be a better fit on the current weed spectrum.

In addition, many of the consultants actually named a specific weed for which they wanted to see as a research focus. Weeds named two or more times by consultants in some part of their written research area included Palmer amaranth (8), barnyardgrass (2), and Italian ryegrass (2).

This survey represented 13%, 28%, 8%, 16%, and 5% of the total soybean area planted in Arkansas, Louisiana, southeast Missouri, Mississippi, and Tennessee, respectively. Of the total scouted area, 78% of the consultants said their growers planted RR soybean in 2016, with 18% planting LL, primarily due to familiarity with and cost of the technology. Glufosinate was determined to be the most effective herbicide in controlling Palmer amaranth by 94% of the consultants. However, they were primarily concerned with controlling herbicide-resistant weeds and the associated cost followed by return profit and time constraints. Palmer amaranth, morningglory species, horseweed, barnyardgrass, and Italian ryegrass were the five most problematic weeds in soybean across the five states. Palmer amaranth was the most problematic and important weed in each state individually. The increased concern with this species was attributed to the rising concern with and occurrence of PPO-resistant Palmer amaranth. Consultants indicated that that more research was needed on cover crops and the new herbicide-resistant soybean traits in order to improve weed management in soybean. The information derived from this survey will allow for the current weed issues in soybean production and for future research needs to be more closely aligned based on grower concerns.

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References

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

Cardina J, Herms CP, Doohan DJ (2002) Crop rotation and tillage system effects on weed seedbanks. Weed Sci 50:448–460

Foresman C, Glasgow L (2008) US grower perceptions and experiences with glyphosate resistant weeds. Pest Manag Sci 64:388–391

Frisvold GB, Hurley TM, Mitchell PD (2009) Adoption of best management practices to control weed resistance by corn, cotton, and soybean growers. Ag Bio Forum 12:370–381

Green JM (2007) Review of glyphosate and ALS-inhibiting herbicide crop resistance and resistant weed management. Weed Technol 21:547–558

Green JM, Owen MDK (2011) Herbicide-resistant crops: utilities and limitations for herbicide resistant weed management. J Agric Food Chem 59:5819–5829

Hager AG, Wax LM, Bollero GA, Stoller EW (2003) Influence of diphenylether herbicide application rate and timing on common waterhemp (*Amaranthus rudis*) control in soybean (*Glycine max*). Weed Technol 17:14–20

Heap I (2017) The International Survey of Herbicide Resistant Weeds. http://www.weedscience.com. Accessed: April 7, 2017

Koger CH, Poston DH, Hayes RMMontgomery RF (2004) Glyphosate-resistant (*Conyza canadensis*) horseweed in Mississippi. Weed Technol 18:820–825

Meyer CJ, Norsworthy JK, Young BG, Steckel LE, Bradley KW, Johnson WG, Loux MM, Davis VM, Kruger GR, Bararpour MT, Ikley JT, Spaunhorst DJ, Butts TR (2015) Herbicide program approaches for managing glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*) and waterhemp (*Amaranthus tuberculatus* and *Amaranthus rudis*) in future soybean-trait technologies. Weed Sci 29:716–729

Nandula VK, Reddy KN, Koger CH, Poston DH, Rimando AM, Duke SO, Bond JA, Ribeiro DN (2012) Multiple resistance to glyphosate and pyrithiobac in Palmer amaranth (*Amaranthus palmeri*) from Mississippi and response to flumiclorac. Weed Sci 60:179–188

Norsworthy JK, Barber LT, Scott RC (2017a) What have we learned after a year of on-farm research on PPO-resistant Palmer amaranth? *In* Proceedings of the Southern Weed Science Society Annual Meeting. Birmingham, AL: Southern Weed Science Society

Norsworthy JK, Griffith G, Griffin T, Bagavathiannan M, Gbur EE (2014) In-field movement of glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*) and its impact on cotton lint yield: evidence supporting a zero-threshold strategy. Weed Sci 62:237–249

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

Norsworthy JK, Owen M, Gunsolus J, Everman WJ, Ervin DE, Frisvold G, Hurley T, Jussaume R, Welcher S (2017b) A survey of BMP adoption for resistance management in U.S. row crops. Abstract 252 *in* Proceedings of the Weed Science Society of America Annual Meeting. Tucson, AZ: Weed Science Society of America

Norsworthy JK, Ward SM, Shaw DR, Llewellyn RS, Nichols RL, Webster TM, Bradley KW, Frisvold G, Powles SB, Burgos NR, Witt WW, Barrett M (2012) Reducing the risks of herbicide resistance: best management practices and recommendations. Weed Sci 60:31–62

Owen MDK, Zelaya IA (2005) Herbicide-resistant crops and weed resistance to herbicides. Pest Manag Sci 61:301–311

Prince JM, Shaw DR, Givens WA, Owen MDK, Weller SC, Young BG, Wilson RG, Jordan DL (2012) Benchmark study. IV. Survey of grower practices for managing glyphosate resistant weed populations. Weed Technol 26:543–548

Reddy KN, Norsworthy JK (2010) Glyphosate-resistant crop production systems: impact on weed species shifts. Pages 165–184 *in* Nandula VK ed, Glyphosate Resistance in Crops and Weeds: History, Development, and Management. Singapore: Wiley

Riar DS, Norsworthy JK, Griffith GM (2011) Herbicide programs for enhanced glyphosate resistant and glufosinate-resistant cotton (*Gossypium hirsutum*). Weed Technol 25:526–534

Riar DS, Norsworthy JK, Steckel LE, Stephenson DO IV, Eubank TW, Bond JA, Scott RC (2013a) Adoption of best management practices for herbicide-resistant weeds in midsouthern United States cotton, rice and soybean. Weed Technol 27:788–797

Riar DS, Norsworthy JK, Steckel LE, Stephenson DO IV, Eubank TW, Scott RC (2013b) Assessment of weed management practices and problem weeds in the Midsouth United States—soybean: a consultant's perspective. Weed Technol 27:612–622

Riggins CW, Tranel PJ (2012) Will the *Amaranthus tuberculatus* resistance mechanism to PPO inhibiting herbicides evolve in other *Amaranthus* species? Inter J Agron Article 2012:10.1155/2012/305764

Schwartz LM, Gibson DJ, Gage KL, Matthews JL, Jordan DL, Owen MDK, Shaw DR, Weller SC, Wilson RG, Young BG (2015) Seedbank and field emergence of weeds in glyphosate-resistant cropping systems in the United States. Weed Sci 63:425–439

Schwartz-Lazaro LM, Norsworthy JK, Scott RCBarber LT (2017) Resistance of two Palmer amaranth populations to multiple herbicide modes of action in Arkansas. Crop Prot 96:158–163

Scott RC, Boyd JW, Selden G, Norsworthy JKBurgos N (2017) Recommended Chemicals for Weed and Brush Control. Little Rock, AR: University of

Arkansas Division of Agriculture Cooperative Extension Service, Miscellaneous Publication. 44
Tharp BE, Kells JJ (2002) Residual herbicides used in combination with glyphosate and glufosinate in corn (*Zea mays*). Weed Technol 16:274–281
Toole EH, Brown E (1946) Final results of the Duvel buried seed experiment. J Agric Res 72:201–210
[USDA-NASS] U.S. Department of Agriculture, National Agricultural Statistics Service. (2016) Acreage. http://usda.mannlib.cornell.edu/usda/current/Acre/Acre-06 30-2016.pdf. Accessed: April 14, 2017
Vail GDOliver LR (1993) Barnyardgrass (*Echinochloa crus-galli*) interference in soybeans (*Glycine max*). Weed Technol 7:220–225
Webster TM (2013) Weed Survey—Southern States. Broadleaf Crops Subsection. Southern Weed Sci Soc Proc 66:275–287
Wuerffel RJ, Young JM, Matthews JL, Young BG (2015) Characterization of PPO-inhibitor resistant waterhemp (*Amaranthus tuberculatus*) response to soil-applied PPO-inhibiting herbicides. Weed Sci 63:511–521

Appendix 1. Soybean Weed Management Survey

Section 1. General information

1. Provide the state and counties where you scout______________________
2. How many soybean acres did you scout this year? ________________ acres
3. How many soybean acres do you anticipate scouting in 2017? ___________ acres
4. What percent of your 2016 scouted soybean acres were planted to the following traits?Roundup Ready® _________________%
   LibertyLink® __________________%
   Roundup Ready® Xtend® _______________%
   Conventional _____________%
5. What percent of your soybean acres were treated at least once during each of the last 3 years with a PPO herbicide? __________%
6. What percent of your acres was treated with a preemergence herbicide? _______________%
7. What was the most commonly applied preemergence herbicide? _________
8. What percent of your acres was treated with a postemergence herbicide? _______________%
9. What was the most commonly applied postemergence herbicide? ________
10. What percent of your acres were treated solely with a single postemergence herbicide such as glyphosate (Roundup®) or glufosinate (Liberty®)? ______________%
11. Excluding a burndown application, what percent of your acres were treated either preemergence or postemergence with one of the following modes of action in 2016?Group 2 (ALS herbicides: Classic®, Envive®, Canopy®, Trivence®, Valor® XLT, others) ________________%
    Group 5 (Tricor®, metribuzin, Authority® MTZ, Boundary®) _________%
    Group 9 (Roundup®, glyphosate) ________________%
    Group 10 (Liberty®, Cheetah®, Interline™, glufosinate) ______________%
    Group 14 (PPO herbicides: Flexstar®, Prefix®, Warrant® Ultra, Valor® XLT, Fierce®, Valor®, Verdict®, all Authority® products) __________%
    Group 15 (Dual, Warrant®, Warrant® Ultra, Zidua®, Prefix®) _________%
12. What percent of your acres were treated in-crop (preemergence and postemergence) with1 mode of action ________________%
    2 modes of action _______________%
    3 or more modes of action _______________%
13. On average, how much did your growers spend on herbicides in the following systems?

a. Roundup Ready® ________________$/acre
b. LibertyLink® _________________ $/acre
c. Conventional __________________$/acre

14. Please provide the percentage of your 2017 acres that you anticipate to be planted to each of the following soybean traits.

a. Roundup Ready® ____________%
b. LibertyLink® _________________%
c. Roundup Ready® Xtend® _____________%
d. Enlist™ ______________________%
e. No trait (conventional) _____________%

15. For your growers that will plant Roundup Ready® soybean in 2017, what is the most likely reason (choose only one)? Circle answer.
    a. Low seed cost
    b. Economics (other than seed costs)
    c. Fear of drift from neighbor
    d. Superior yields
    e. Ability to control resistant weeds
    f. Complexity of the application requirements on new technologies
    g. Other (please specify): ______________________________________

16. For your growers that will plant LibertyLink® soybean in 2017, what is the most likely reason (choose only one)? Circle answer.
    a. Low seed cost
    b. Economics (other than seed costs)
    c. Fear of drift from neighbor
    d. Superior yields
    e. Ability to control resistant weeds
    f. Complexity of the application requirements on new technologies
    g. Other (please specify): ______________________________________

17. For your growers that will plant Roundup Ready® Xtend® soybean in 2017, what is the most likely reason (choose only one)? Circle answer.
    a. Low seed cost
    b. Economics (other than seed costs)
    c. Fear of drift from neighbor
    d. Superior yields
    e. Ability to control resistant weeds
    f. Complexity of the application requirements on new technologies
    g. Other (please specify): ______________________________________

18. For your growers that will plant Enlist™ soybean in 2017, what is the most likely reason (choose only one)? Circle answer.
    a. Low seed cost
    b. Economics (other than seed costs)
    c. Fear of drift from neighbor
    d. Superior yields
    e. Ability to control resistant weeds
    f. Complexity of the application requirements on new technologies
    g. Other (please specify): ______________________________________

19. For your growers that will plant conventional soybean in 2017, what is the most likely reason? Choose one answer.
    a. Low seed cost
    b. Economics (other than seed costs)
    c. Fear of drift from neighbor
    d. Superior yields
    e. Ability to control resistant weeds
    f. Complexity of the application requirements on new technologies
    g. Other (please specify): ______________________________________

20. Please rate the average effectiveness (or anticipated effectiveness) of the following postemergence herbicides alone on 4-inch tall Palmer amaranth today using the following categories (Excellent, Good, Fair, Poor, No Control).
    a. Roundup® __________________________
    b. Classic® (ALS herbicide)____________________________
    c. Flexstar® or Reflex (PPO herbicide) ________________________
    d. Liberty® ___________________________
    e. Dicamba ___________________________
    f. Enlist Duo® (Roundup® + 2,4-D choline) ___________________

21. If an extremely effective herbicide were to be made available, which scenario do you think would most likely occur? Choose one answer.
    a. Most farmers would blend its use with other weed management practices, including cultural practices.

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b. Most farmers would use it exclusively until its effectiveness diminished.
c. Most farmers would use it in combination with other herbicides.

Section 2. Herbicide resistance

1. Rank in order (1 = greatest to 7 = least) the obstacles your growers face in adequately adopting herbicide-resistance management strategies.
___________ Weather
___________ Cost
___________ Time constraints
___________ Lack of labor/trained employees
___________ Profit
___________ Complacency
___________ Availability of equipment
2. Choose the three management practices for herbicide resistance that are most widely adopted by your growers
   a. Start clean
   b. Proper herbicide timing
   c. Multiple effective herbicide modes of action
   d. Full labeled herbicide rates
   e. Soil seedbank management
   f. Crop rotation
   g. Trait rotation
   h. Tillage (disk, cultivation, or deep tillage)
   i. Cultural practices (narrow rows, cover crops, hand weeding, narrow-windrow burning)
   j. Sanitation (cleaning equipment, planting weed-free seed)
3. Which one of the following practices do you expect to see the greatest increase in adoption over the next 5 years? Choose one answer.
   a. Start clean
   b. Proper herbicide timing
   c. Multiple effective herbicide modes of action
   d. Full labeled herbicide rates
   e. Soil seedbank management
   f. Crop rotation
   g. Trait rotation
   h. Tillage (disk, cultivation, or deep tillage)
   i. Cultural practices (narrow rows, cover crops, hand-weeding, narrow-windrow burning)
   j. Sanitation (cleaning equipment, planting weed-free seed)
4. Which of the following resistance management practices do you believe may decrease over the next 3 years? Check all that apply.
   a. Start clean
   b. Proper herbicide timing
   c. Multiple effective herbicide modes of action
   d. Full labeled herbicide rates
   e. Soil seedbank management
   f. Crop rotation
   g. Trait rotation
   h. Tillage (disk, cultivation, or deep tillage)
   i. Cultural practices (narrow rows, cover crops, hand-weeding, narrow-windrow burning)
   j. Sanitation (cleaning equipment, planting weed-free seed)
5. Please explain why you perceive that the above practices will decrease.
____
____
____
____

6. Of these cultural practices, which one do you perceive as having the greatest impact on reducing herbicide resistance?
   a. Drill-seeded soybean
   b. Cover crops
   c. Hand weeding
   d. Narrow-windrow burning
7. How will grower adoption of Roundup Ready® Xtend® soybean impact use of best management practices for resistance?
____
____
____
____

Section 3. Most problematic/troublesome weeds

1. Give the following weeds a number associated with management importance. 1 = not important, 2 = rarely important, 3 = occasionally important, 4 = important, and 5 = very important.
Annual bluegrass
Barnyardgrass
Bermudagrass
Broadleaf signalgrass
Browntop millet
Carolina geranium
Chickweed
Common cocklebur
Common lambsquarters
Common purslane
Common ragweed
Crabgrass
Curly dock
Cutleaf evening-primrose
Eclipta
Fall panicum
Giant ragweed
Goosegrass
Groundcherries
Hemp sesbania
Henbit
Hophornbeam copperleaf
Horseweed
Italian ryegrass
Johnsongrass
Morningglories
Palmer amaranth
Prickly sida
Red rice
Redvine
Shepherd's-purse
Sicklepod
Smartweeds
Spotted spurge
Spurred anoda
Velvetleaf
Waterhemp
Yellow nutsedge
2. What are your three most problematic weeds in soybean?

Section 4. PPO-resistant Palmer amaranth

1. Rate your concern with PPO-resistant Palmer amaranth. Circle most appropriate answer.
   a. None b. Slight c. Moderate d. High
2. Do you suspect PPO-resistant Palmer amaranth on the farms that you scout? _____yes _____no
3. If you answered yes to the previous question, on what percent of your scouted acres have you observed PPO-resistant Palmer amaranth?
4. Do you expect tillage to increase on your farms as a result of PPO-resistant Palmer amaranth? _____yes _____no
5. What are you recommending to growers who have PPO-resistant Palmer amaranth?

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____
____
____
____

Section 5. Describe two areas where you would like to see weed scientists in your state increase their research focus.

a.
____
____
____
____

b.
____
____
____
____