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WEED SCIENCE

Cotton Response and Palmer Amaranth Control with Mixtures of Glufosinate and Residual Herbicides

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ABSTRACT

Recommendations to control glyphosate-resistant Palmer amaranth (*Amaranthus palmeri* S. Wats.) in cotton (*Gossypium hirsutum* L.) typically include glufosinate applied postemergence (POST) and residual herbicides applied both preemergence and POST. Residual herbicide options for POST application are limited primarily to pyrithiobac and the chloroacetamides herbicides acetochlor and *S*-metolachlor. Labeling for pyrithiobac warns of injury when mixed with metolachlor. No published information is available on crop or weed response to mixtures of glufosinate plus acetochlor, with or without pyrithiobac. Tolerance of WideStrike® cotton and Palmer amaranth control with glufosinate applied alone to 1- to 2-leaf cotton, glufosinate mixed with pyrithiobac or micro-encapsulated acetochlor or *S*-metolachlor, and three-way combinations of glufosinate plus acetochlor or *S*-metolachlor plus pyrithiobac were evaluated in field experiments. These treatments were followed by a second application of glufosinate and diuron plus MSMA directed at layby. Prior to the second application, glufosinate early POST alone controlled Palmer amaranth 77%. Pyrithiobac mixed with glufosinate increased control 10 to 11%, whereas acetochlor and *S*-metolachlor increased control 12 to 14%. Control was similar with glufosinate plus acetochlor with or without pyrithiobac, whereas combinations of glufosinate plus *S*-metolachlor plus pyrithiobac were 4 to 5% more effective than glufosinate plus *S*-metolachlor. Pyrithiobac increased cotton necrosis 3 to 4% and reduced growth 5% 7 d after application compared to glufosinate alone. Acetochlor and *S*-metolachlor increased necrosis 14 to 18% and reduced growth 7 to 10%. Necrosis was similar with glufosinate plus acetochlor with or without pyrithiobac. Pyrithiobac added to glufosinate plus *S*-metolachlor increased necrosis 3 to 4%. Injury was transient, and no differences in lint yield were noted among herbicide treatments.

Palmer amaranth (*Amaranthus palmeri* S. Wats.) is the most troublesome weed in cotton (*Gossypium hirsutum* L.) and other agronomic crops in the southern U.S. (Webster, 2013). The biology of this weed, its impact on cotton yield, and the difficulty of control in cotton were reviewed by Culpepper et al. (2010). High rates of photosynthesis, rapid growth, large plant stature, and drought tolerance mechanisms give Palmer amaranth a competitive advantage over cotton (Ehleringer, 1983, 1985; Horak and Loughin, 2000; Place et al., 2008; Sellers et al., 2003; Wright et al., 1999). Palmer amaranth can dramatically reduce cotton yield, with yield reductions up to 92% with eight weeds m^{-1} of row (MacRae et al., 2013; Morgan et al., 2001; Rowland et al., 1999). It can also interfere with or prevent mechanical harvest (Morgan et al., 2001; Smith et al., 2000). Prolific seed production allows dense populations to build up quickly (Bensch et al., 2003; Burke et al., 2007; Inman et al., 2014; MacRae et al., 2013; Norsworthy et al., 2014). Continued plant emergence and seed production throughout the season enable the weed to replenish seed banks if control is not season long (Jha and Norsworthy, 2009; Keely et al., 1987; MacRae et al., 2013).

Glyphosate-resistant (GR) cotton cultivars, commercially released in 1997, revolutionized weed management in cotton (Culpepper and York, 1998, 1999; Faircloth et al., 2001; Gianessi, 2008) and the technology was quickly adopted by growers. Ninety-eight percent of cotton in Arkansas and Georgia and greater than 99% in other states in the Southeast and Mid-South regions of the U.S. Cotton Belt were planted to cultivars resistant to glyphosate or glyphosate and glufosinate in 2013 (USDA-AMS, 2014).

Traditionally, glyphosate offered superior Palmer amaranth control (Bond et al., 2006; Corbett et al., 2004; Culpepper and York, 1998, 1999; Scott et al.,

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2002), and cotton growers relied heavily on glyphosate while reducing their use of other herbicides (Givens et al., 2009; Sosnoskie and Culpepper, 2014; Wilson et al., 2011). Excessive reliance on glyphosate led to selection for resistant biotypes. Resistance to glyphosate has now been confirmed in 32 and 14 weed species globally and in the U.S., respectively (Heap, 2015). The first confirmation of resistance to glyphosate in an *Amaranthus* species occurred with Palmer amaranth in Georgia in 2005 (Culpepper et al., 2006). By the end of 2014, GR Palmer amaranth had been confirmed in 24 U.S. states (Heap, 2015).

Growers have resumed use of residual herbicides in an effort to control GR Palmer amaranth (Sosnoskie and Culpepper, 2014). Many growers, especially in the southeastern U.S., also are planting glufosinate-resistant cotton cultivars and relying upon glufosinate to control GR Palmer amaranth (Sosnoskie and Culpepper, 2014; USDA-AMS, 2014). Glufosinate, applied timely, controls Palmer amaranth (Barnett et al., 2013; Corbett et al., 2004; Culpepper et al., 2009; Reed et al., 2014; Whitaker et al., 2011). Barnett et al. (2013) reported glufosinate controlled 13-cm tall Palmer amaranth 89%, whereas the herbicide controlled 26-cm tall Palmer amaranth 59%. Previous research also demonstrated that 2- to 5-cm tall Palmer amaranth was more easily controlled by glufosinate than 8- to 10-cm tall Palmer amaranth (Corbett et al. 2004). Residual herbicides, such as acetochlor, *S*-metolachlor, and pyrithiobac, mixed with glufosinate or glyphosate applied postemergence (POST), are commonly recommended (Burgos et al., 2006; Culpepper, 2015; York, 2015). Compared to glyphosate or glufosinate applied alone, these residual herbicides can increase control of susceptible species, including Palmer amaranth (Batla et al., 2010; Clewis et al., 2006, 2008; Culpepper et al., 2004, 2009; Everman et al., 2007; Whitaker et al., 2011; Wilson et al., 2007). Crop injury is typically observed when one of the aforementioned residual herbicides is mixed with glyphosate or glufosinate, but the injury is transient and cotton yield is unaffected (Clewis et al., 2006; Culpepper et al., 2009; Stephenson et al., 2013; Whitaker et al., 2011).

A three-way mixture of glyphosate or glufosinate plus pyrithiobac plus acetochlor or *S*-metolachlor can control a broader spectrum of weeds and increase herbicide diversity in management systems (Stephenson et al., 2013). Labeling for the products that could be used in these three-way combinations is not helpful to the practitioner deciding which combinations should or should not be considered. Labeling for glyphosate (Anonymous, 2015a) allows glyphosate to be mixed with acetochlor, *S*-metolachlor, or pyrithiobac, and there are no precautions against three-way mixtures. Labeling for glufosinate (Anonymous, 2015b) allows glufosinate to be mixed with *S*-metolachlor or pyrithiobac, again with no precautions against three-way mixtures. Labeling for acetochlor (Anonymous, 2015c) specifically mentions mixtures of acetochlor with glyphosate or pyrithiobac and there are no precautions against three-way mixtures. Labeling for *S*-metolachlor, in the context of mixtures of *S*-metolachlor and glyphosate, simply precautions against adding other pesticides (Anonymous, 2015d). Only the labeling for pyrithiobac (Anonymous, 2015e) is specific concerning these mixtures. That labeling allows for mixtures of pyrithiobac plus glyphosate or glufosinate but specifically states that pyrithiobac should not be co-applied with a herbicide containing metolachlor as crop injury might result. As pointed out by Stephenson et al. (2013), published research on the utility and risks of such three-way combinations is limited. Stephenson et al. (2013) observed 31% cotton injury 3 d after application of pyrithiobac plus *S*-metolachlor plus glyphosate compared with 17 and 7% injury by pyrithiobac plus glyphosate and *S*-metolachlor plus glyphosate, respectively. Cotton was also slower to recover from the three-way mixture of pyrithiobac plus *S*-metolachlor plus glyphosate. Injury declined to 5% or less at 7, 14, and 21 d after application of *S*-metolachlor plus glyphosate, pyrithiobac plus glyphosate, and *S*-metolachlor plus pyrithiobac plus glyphosate, respectively. In spite of the injury, cotton yield was unaffected.

No research has been published on cotton response and weed control with mixtures of glufosinate plus acetochlor or mixtures of glufosinate plus *S*-metolachlor plus pyrithiobac. The objective of our research was to evaluate cotton tolerance and weed control with glufosinate applied in two- and three-way mixtures with acetochlor, pyrithiobac, and *S*-metolachlor.

MATERIALS AND METHODS

The experiment was conducted in North Carolina six times during 2011 and 2012 at the Central Crops Research Station at Clayton and on private farms at Micro and Mount Olive. Soils are described in Table 1. Humic matter was determined according to Mehlich (1984) by the Agronomic Services Division of the North Carolina Department of Agriculture and Consumer Services. Adjacent areas of the same field were used at Mount Olive in 2011 and 2012. A conventional tillage system consisting of disking followed by bed formation with in-row subsoiling was used at Micro and Clayton. The Mount Olive location was a no-till system. At Mount Olive, a wheat (*Triticum aestivum* L.) cover crop was desiccated 3 wk prior to planting with glyphosate (Roundup PowerMAX®, Monsanto Company, St. Louis, MO) at 1260 g ae ha^{-1} plus 2,4-D (Weedar® 64, Nufarm Agricultural Products, Alsip, IL) at 530 g ae ha^{-1}. Paraquat (Parazone® 3SL, ADAMA Agriculture Solutions, Raleigh, NC) at 840 g ae ha^{-1} also was applied following planting to control any emerged weeds. Each location was naturally infested with Palmer amaranth at densities of 30 to 40 plants m^{-2} at Clayton Fields 2 and 3 and greater than 100 plants m^{-2} at the other locations.

Cotton cultivars utilized in this study were 'PHY 375WRF' or 'PHY 499WRF' (Dow AgroSciences, Indianapolis, IN) and their planted dates are listed in Table 1. Both varieties contain the WideStrike® trait, which confers tolerance to topical applications of glufosinate, although slight injury is possible (Barnett et al., 2013; Culpepper et al., 2009; Steckel et al., 2012; Whitaker et al., 2011). Aldicarb insecticide (Bayer CropScience, Research Triangle Park, NC) was applied at 840 g ai ha^{-1} in the seed furrow at all locations. The experimental design was a randomized complete block with treatments replicated four times. Plots were four rows by 9 m with row spacing of 97 cm.

Treatments consisted of glufosinate (Liberty® 280 SL, Bayer CropScience, Research Triangle Park, NC) at 543 g ae ha^{-1} alone or in combination with residual herbicides applied early postemergence (EPOST) 16 to 22 d after planting to 1- to 2-leaf cotton. Palmer amaranth was 5- to 10-cm tall at EPOST application. Residual herbicides and herbicide combinations included the following: a micro-encapsulated formulation of acetochlor (Warrant® Herbicide, Monsanto Company, St. Louis, MO) at 1260 g ai ha^{-1}; *S*-metolachlor (Dual Magnum® Herbicide, Syngenta Crop Protection, Greensboro, NC) at 1067 g ai ha^{-1}; pyrithiobac (Staple® LX, DuPont Crop Protection, Wilmington, DE) at 48 and 77 g ai ha^{-1} (hereafter referred to as pyrithiobac low and pyrithiobac high, respectively); acetochlor 1260 g ha^{-1} plus pyrithiobac low or pyrithiobac high; and *S*-metolachlor plus pyrithiobac low or pyrithiobac high. The EPOST application was followed by a mid-postemergence (MPOST) application of glufosinate at 543 g ha^{-1} 13 to 25 d after EPOST when cotton had 3 to 6 leaves, depending upon location. Timing of the MPOST application was targeted to Palmer amaranth less than 10-cm tall. The MPOST application was followed 14 to 16 d later by a postemergence-directed (PDIR) application of diuron (Direx® 4L, ADAMA Agriculture Solutions, Raleigh, NC) at 840 g ai ha^{-1} plus MSMA (MSMA 6 Plus, Drexel Chemical Co., Memphis, TN) at 2100 g ai ha^{-1}. A non-treated plot was included for comparison. The EPOST and MPOST herbicides were applied using a CO_2-pressurized backpack sprayer equipped with flat-fan nozzles (DG11002, TeeJet Technologies, Wheaton, IL) set to deliver 140 L ha^{-1} at 165 kPa. The PDIR herbicides were broadcast using a single flood nozzle (TK-VS2, TeeJet Technologies, Wheaton, IL) per row delivering 140 L ha^{-1} at 210 kPa.

Table 1. Soils, tillage systems, varieties planted, and planting dates at experiment sites

Location	Year	Soil series and texture	Humic matter %	Tillage system	Variety	Planting date
Clayton; Field 1	2011	Lynchburg sandy loam[z]	1.1	Conventional	PHY 375WRF[v]	May 12
Clayton; Field 2	2011	Norfolk loamy sand[y]	1.0	Conventional	PHY 375 WRF	May 12
Mount Olive	2011	Wagram loamy sand[x]	0.5	No-till	PHY 499WRF[v]	May 11
Clayton; Field 3	2012	Norfolk loamy sand	0.5	Conventional	PHY 499WRF	May 2
Micro	2012	Faceville sandy loam[w]	0.6	Conventional	PHY 499WRF	May 22
Mount Olive	2012	Wagram loamy sand	0.7	No-till	PHY 499WRF	May 7

[z] Fine-loamy, siliceous, thermic Aeric Paleaquults.

[y] Fine-loamy, kaolinitic, thermic Typic Kandiudults.

[x] Loamy, kaolinitic, thermic Arenic Kandiudults.

[w] Fine, kaolinitic, thermic Typic Kandiudults.

[v] Dow AgroSciences, Indianapolis, IN.

Weed control and cotton injury were estimated visually on a 0 to 100 scale according to Frans et al. (1986), where 0 = no weed control or no plant injury and 100 = complete weed control or plant death. Percent cotton injury (necrosis and growth reduction recorded separately) was estimated 7 and 14 d after EPOST, 14 d after MPOST, and 14 d after PDIR. Weed control was estimated 7 d after EPOST, at the time of MPOST application, 14 d after MPOST, and late in the season (mid-September, prior to defoliation). Palmer amaranth shoot fresh weight was determined following the late-season control rating. Weeds from 1 m^2 in the non-treated plot and from three row middles (22 to 28 m^2) in treated plots were clipped at the soil surface and weighed. Cotton was mechanically harvested and a sample of the harvested seed cotton was collected from each plot and ginned to determine lint percentage. Lint was subjected to high volume instrument (HVI) analysis to determine upper-half mean fiber length, fiber length uniformity, fiber strength, and micronaire (Ramey, 1999). The HVI analysis was performed by Cotton Incorporated in Cary, NC. The non-treated plots were too weedy to harvest but visually there appeared to be little to no lint present. Yield of the non-treated plots were assumed to be zero, and the data were not included in statistical analyses. Data were subjected to analysis of variance using the PROC MIXED procedure of SAS (version 9.3; SAS Institute Inc., Cary, NC). Herbicide treatments and locations were considered as fixed factors, whereas replications were treated as random. Data were averaged over locations when appropriate, and means were separated using Fisher's Protected LSD at $p = 0.05$. Dunnett's procedure (Dunnett, 1955) was used to compare Palmer amaranth fresh weights in the non-treated to all other treatments.

RESULTS AND DISCUSSION

Glufosinate alone applied EPOST controlled Palmer amaranth 85% 7 d after EPOST application, but control declined to 77% at time of MPOST application (13 to 25 d after EPOST) primarily because of additional weed emergence (Table 2). Palmer amaranth was controlled 86% 14 d after MPOST glufosinate application and 94% late in the season after two POST applications of glufosinate and a layby application of diuron plus MSMA. Glufosinate and layby herbicides were applied timely (Palmer amaranth less than 10 cm), while weeds were small, allowing for good spray coverage and effective late-season control. Similar late-season Palmer amaranth control following two well-timed glufosinate applications followed by a layby herbicide application has been reported (Culpepper et al., 2009; Gardner et al., 2006; Whitaker et al. 2011).

Table 2. Palmer amaranth control and fresh weight with residual herbicides mixed with glufosinate[z]

Residual herbicides[y]		Control				Fresh weight[x] g ha^{-1}
Acetochlor or *S*-metolachlor	Pyrithiobac	7 d EPOST	At MPOST	At LPOST	Late-season	
		%				
none	none	85 c	77 d	86 d	94 d	930 a
none	pyrithiobac, low	93 b	87 c	91 c	97 b	230 b
none	pyrithiobac, high	94 b	88 bc	91 c	97 b	400 b
acetochlor	none	94 b	91 ab	93 b	97 b	360 b
s-metolachlor	none	94 b	89 bc	92 bc	96 c	430 b
acetochlor	pyrithiobac, low	96 a	90 bc	95 a	98 a	190 b
acetochlor	pyrithiobac, high	97 a	94 a	96 a	98 a	280 b
s-metolachlor	pyrithiobac, low	97 a	94 a	95 a	97 b	200 b
s-metolachlor	pyrithiobac, high	96 a	93 a	95 a	98 a	160 b

[z] Data averaged over six locations. Means within a column followed by the same letter are not different according to Fisher's Protected LSD Test at $p = 0.05$. Glufosinate applied EPOST (1- to 2-leaf cotton) and MPOST (3- to 8-leaf cotton, 13 to 25 d after EPOST) at 543 g ha^{-1}. Diuron at 840 g ha^{-1} plus MSMA at 2100 g ha^{-1} applied PDIR 14 d after MPOST.

[y] Residual herbicides applied EPOST in combination with glufosinate. Acetochlor, *S*-metolachlor, pyrithiobac low, and pyrithiobac high applied at 1260, 1067, 48, and 77 g ha^{-1}, respectively.

[x] Palmer amaranth fresh weight in non-treated controls was 19,720 kg ha^{-1}. Fresh weight of non-treated controls differed from all herbicide treatments according to Dunnett's procedure at $p = 0.05$. Dunnett's procedure at $p < 0.05$.

Palmer amaranth response to the residual herbicides was similar at all evaluations. Individual residual herbicides applied with glufosinate increased control 8 to 9, 10 to 14, 5 to 7, and 2 to 3% at 7 d after EPOST, at MPOST, 14 d after MPOST, and late in the season, respectively (Table 2). Pyrithiobac was similarly effective when applied at the low and high rates, controlling Palmer amaranth throughout the season 87 to 97 and 88 to 97%, respectively. Acetochlor and *S*-metolachlor also were similarly effective. Throughout the season, acetochlor controlled Palmer amaranth 91 to 97%, whereas *S*-metolachlor controlled the weed 89 to 96%. Differences in control between glufosinate plus pyrithiobac and glufosinate plus either acetochlor or *S*-metolachlor were minor. Two-way combinations of glufosinate and a single residual herbicide controlled Palmer amaranth 93 to 94, 87 to 91, 91 to 93, and 96 to 97% 7 d after EPOST, at MPOST, 14 d after MPOST, and late in the season, respectively. Three-way combinations of glufosinate plus pyrithiobac plus acetochlor or *S*-metolachlor were only marginally more effective than two-way combinations of glufosinate plus any of the residual herbicides. Three-way combinations controlled Palmer amaranth 96 to 97, 90 to 94, 95 to 96, and 97 to 98% 7 d after EPOST, at MPOST, 14 d after MPOST, and late in the season, respectively. Palmer amaranth fresh weight late in the season followed the same trends as the visual estimates of control. All residual herbicides reduced fresh weight compared to glufosinate alone, although there were no differences among residual herbicides. Compared to the non-treated, glufosinate alone reduced Palmer amaranth fresh weight 95% whereas glufosinate plus residual herbicides reduced fresh weight 98 to 99% (Table 2).

Cotton injury was observed as 5% necrosis and 1% growth reduction 7 d after EPOST glufosinate application (DAT) (Table 3). A similar effect was noted following the MPOST glufosinate application (data not shown). Necrosis and growth reduction 7 DAT were increased 3 to 4% and 5%, respectively, when pyrithiobac was applied with glufosinate. Acetochlor and *S*-metolachlor in combination with glufosinate caused 19 and 23% necrosis, respectively, and 11 and 8% growth reduction, respectively, 7 DAT. Similar levels of injury were reported previously in North Carolina with combinations of glufosinate plus pyrithiobac or glufosinate plus *S*-metolachlor applied to WideStrike® cotton (Whitaker et al., 2011). Necrosis following the three-way combinations of glufosinate plus acetochlor plus pyrithiobac was greater than combinations of glufosinate plus pyrithiobac, but similar to necrosis following glufosinate plus acetochlor 7 DAT (Table 3). Necrosis was 3 to 4% greater with combinations of glufosinate plus *S*-metolachlor plus pyrithiobac compared with glufosinate plus *S*-metolachlor. Glufosinate plus *S*-metolachlor and glufosinate plus acetochlor reduced cotton growth 8 and 11% 7 DAT, respectively. Similarly, three-way combinations of glufosinate plus pyrithiobac plus *S*-metolachlor and glufosinate plus pyrithiobac plus acetochlor reduced cotton growth 9 to 10 and 10 to 12%, respectively. Less necrosis and growth reduction were noted 14 DAT, and little to no injury from the residual herbicides was noted at later evaluations (data not shown).

Table 3. Cotton injury from early postemergence (EPOST) application of glufosinate mixed with residual herbicides[z]

Residual herbicides[y]		Necrosis		Growth reduction	
Acetochlor or *S*-metolachlor	Pyrithiobac	7 DAT[x]	14 DAT	7 DAT	14 DAT
		%			
none	none	5 e	3 e	1 e	2 c
none	pyrithiobac, low	8 d	3 e	6 d	3 bc
none	pyrithiobac, high	9 d	4 d	6 d	2 c
acetochlor	none	19 c	11 b	11 ab	7 a
s-metolachlor	none	23 b	10 c	8 cd	7 a
acetochlor	pyrithiobac, low	20 c	11 b	12 a	6 a
acetochlor	pyrithiobac, high	20 c	12 a	10 abc	5 ab
s-metolachlor	pyrithiobac, low	26 a	11 b	9 bc	7 a
s-metolachlor	pyrithiobac, high	27 a	12 a	10 abc	6 a

[z] Data averaged over six locations. Glufosinate applied EPOST to 1- to 2-leaf cotton at 543 g ha^{-1}. Means within a column followed by the same letter are not different according to Fisher's Protected LSD Test at $p = 0.05$.

[y] Residual herbicides applied EPOST in combination with glufosinate. Acetochlor, *S*-metolachlor, pyrithiobac low, and pyrithiobac High applied at 1260, 1067, 48, and 77 g ha^{-1}, respectively.

[x] DAT, days after treatment.

Cotton lint yield, averaged over locations, ranged from 1300 to 1410 kg ha^{-1} and did not differ among herbicide treatments (data not shown). There also were no differences among herbicide treatments for the cotton fiber quality parameters measured. Averaged over treatments and locations, upper-half mean fiber length, fiber length uniformity, fiber strength, and micronaire were 26.6 mm, 78.1%, 281 kN m kg^{-1}, and 4.5, respectively (data not shown). Except for situations where herbicides delay cotton fruiting and maturity (Byrd and York, 1987; Guthrie and York, 1989; Shankle et al., 1996), weed management programs seldom impact fiber quality (Culpepper and York, 1999; Gardner et al., 2006; Jordan et al., 1993; Richardson et al., 2006; Steckel et al., 2012; Whitaker et al., 2011).

Increases in Palmer amaranth control resulting from residual herbicides added to glufosinate were minimal, ranging 2 to 14% throughout the season, and did not impact yield. However, Palmer amaranth is an extremely prolific seed producer and large seed banks can develop quickly (Keeley et al., 1987; MacRae et al., 2013; Norsworthy et al., 2014; Smith et al., 2000). The dense populations typical of infested fields significantly contribute to the difficulty and complexity of management. Sustainable management of this weed will require depletion of the seed bank, and weed scientists are now promoting a zero tolerance policy for seed production (Crow et al., 2015; Norsworthy et al., 2014). Palmer amaranth seed have relatively short longevity in soil. Research has shown the seed bank can be nearly depleted in 4 yr if further seed production is prevented (Jha et al., 2014; Sosnoskie et al., 2013). However, a few escaped weeds can replenish the seed bank (Bensch et al., 2003). The small increases in control in this study due to the residual herbicides added to glufosinate, although not having an immediate economic impact, might well have a significant long-term impact. Furthermore, residual herbicides are essential to resistance management. Overlapping residual herbicides throughout the season reduces the selection pressure on heavily used POST herbicides by limiting the number of weeds exposed to these products (Norsworthy et al. 2012).

There was no evidence from this study to discourage adding pyrithiobac to mixtures of glufosinate plus acetochlor. Cotton injury was similar with three-way mixtures of glufosinate plus acetochlor plus pyrithiobac and mixtures containing only glufosinate plus acetochlor. Although labeling for pyrithiobac (Anonymous, 2015e) warns of greater injury when pyrithiobac is mixed with metolachlor, injury by three-way combinations of glufosinate plus *S*-metolachlor plus pyrithiobac in this study was only marginally greater than injury by glufosinate plus *S*-metolachlor and did not impact yield.

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