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Controlling Glyphosate-Resistant Palmer Amaranth (*Amaranthus palmeri*) in Cotton with Resistance to Glyphosate, 2,4-D, and Glufosinate

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Field experiments were conducted in Macon County, Georgia, during 2010 and 2011 to determine the impact of new herbicide-resistant cotton and respective herbicide systems on the control of glyphosate-resistant Palmer amaranth. Sequential POST applications of 2,4-D or glufosinate followed by diuron plus MSMA directed at layby (late POST-directed) controlled Palmer amaranth 62 to 79% and 46 to 49% at harvest when the initial application was made to 8- or 18–cm-tall Palmer amaranth, in separate trials, respectively. Mixtures of glufosinate plus 2,4-D applied sequentially followed by the layby controlled Palmer amaranth 95 to 97% regardless of Palmer amaranth height. Mixing glyphosate with 2,4-D improved control beyond that observed with 2,4-D alone, but control was still only 79 to 86% at harvest depending on 2,4-D rate. Sequential applications of glyphosate plus 2,4-D controlled Palmer amaranth 95 to 96% following the use of either pendimethalin or fomesafen. Seed cotton yield was at least 30% higher with 2,4-D plus glufosinate systems compared to systems with either herbicide alone. The addition of pendimethalin and/or fomesafen PRE did not improve Palmer amaranth control or yields when glufosinate plus 2,4-D were applied sequentially followed by the layby. The addition of these residual herbicides improved at harvest control (87 to 96%) when followed by sequential applications of 2,4-D or 2,4-D plus glyphosate; yields from these systems were similar to those with glufosinate plus 2,4-D. Comparison of 2,4-D and 2,4-DB treatments confirmed that 2,4-D is a more effective option for the control of Palmer amaranth. Results from these experiments suggest cotton with resistance to glufosinate, glyphosate, and 2,4-D will improve Palmer amaranth management. At-plant residual herbicides should be recommended for consistent performance of all 2,4-D systems across environments, although cotton with resistance to glyphosate, glufosinate, and 2,4-D will allow greater flexibility in selecting PRE herbicide(s), which should reduce input costs, carryover concerns, and crop injury when compared to current systems.

Nomenclature: 2,4-D; 2,4-DB; diuron; glufosinate; glyphosate; MSMA; Palmer amaranth, *Amaranthus palmeri* (S.) Wats. AMAPA; cotton, *Gossypium hirsutum* L.

Key words: Resistance management, tank mixtures, sequential herbicide applications.

Experimentos de campo fueron realizados en el condado Macon, Georgia, durante 2010 y 2011 para determinar el impacto de nuevos sistemas de algodón resistentes a herbicidas y sus respectivos herbicidas en el control de *Amaranthus palmeri* resistente a glyphosate. Aplicaciones secuenciales POST de 2,4-D o glufosinate seguidas de diuron más MSMA dirigidas a la base del cultivo (aplicaciones POST dirigidas tarde en el ciclo de crecimiento) controlaron *A. palmeri* 62 a 79% y 46 a 49% al momento de la cosecha cuando la aplicación inicial se hizo a *A. palmeri* de 8 a 18 cm de altura, en estudios independientes, respectivamente. Mezclas de glufosinate más 2,4-D aplicados secuencialmente seguidos por la aplicación dirigida controlaron *A. palmeri* 95 a 97% sin importar la altura de la maleza. El mezclar glyphosate con 2,4-D mejoró el control más allá del control observado con 2,4-D solo, pero aún así el control fue solamente 79 a 86% al momento de la cosecha, dependiendo de la dosis de 2,4-D. Aplicaciones secuenciales de glyphosate más 2,4-D controlaron *A. palmeri* 95 a 96% cuando se usaron después de aplicaciones de pendimethalin o fomesafen. El rendimiento de semilla del algodón fue al menos 30% mayor en sistemas con 2,4-D más glufosinate en comparación con los sistemas que tuvieron solamente aplicaciones de cualquiera de estos dos herbicidas solos. La adición de pendimethalin y/o fomesafen PRE no mejoró el control de *A. palmeri* ni los rendimientos cuando se realizaron aplicaciones secuenciales de glufosinate más 2,4-D seguidas por aplicaciones dirigidas. La adición de estos herbicidas residuales mejoró el control al momento de la cosecha (87 a 96%) cuando fueron seguidos de aplicaciones secuenciales de 2,4-D o 2,4-D más glyphosate. Los rendimientos de estos sistemas fueron similares a los de glufosinate más 2,4-D. Comparaciones entre tratamientos de 2,4-D y 2,4-DB confirmaron que 2,4-D es una opción más efectiva para el control de *A. palmeri*. Los resultados de estos experimentos

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sugieren que el algodón con resistencia a glufosinate, glyphosate, y 2,4-D mejorará el manejo de *A. palmeri*. El uso de herbicidas residuales debería ser recomendado para promover un desempeño consistente de todos los sistemas con 2,4-D en diferentes ambientes, aunque el algodón con resistencia a glyphosate, glufosinate, y 2,4-D permitirá una mayor flexibilidad en la selección de herbicidas PRE, lo cual podría reducir el costo en insumos, las preocupaciones por limitaciones en la rotación de cultivos debido a larga residualidad, y el riesgo de daño del cultivo, en comparación con los sistemas actuales.

First confirmed in 2004, glyphosate-resistant Palmer amaranth remains the primary weed of concern for cotton producers (Culpepper et al. 2006; Culpepper et al. 2010; Gaines et al. 2011; Whitaker et al. 2011a, 2011b). Efforts to control this pest have become more successful, but remain challenging and costly (Ford et al. 2011; Neve et al. 2011; Price et al. 2011). A grower survey conducted in 2010 reported that Georgia growers are spending \$168 ha^{-1} on herbicides for the control of glyphosate-resistant Palmer amaranth, 2.5 times more herbicide active ingredient than they applied prior to resistance confirmation (Sosnoskie and Culpepper 2012). Use of residual herbicides (acetochlor, diuron, flumioxazin, fomesafen, pendimethalin, trifluralin, and *S*-metolachlor) applied throughout the crop as well as use of paraquat for preplant burndown and glufosinate for topical in-crop applications have increased. In conjunction with increased glufosinate use has been the adoption of cotton cultivars resistant to topical applications of glufosinate; increasing from 0% of Georgia's hectares in 2004 up to 49% of the hectares during 2012 (U.S. Department of Agriculture [USDA] 2004, 2012). Even after an aggressive herbicide system, 92% of Georgia growers are hand weeding 52% of the cotton crop at an average cost of \$60 ha^{-1} for each hand-weeded hectare. Loss of conservation tillage is also occurring as growers adopt both primary and secondary tillage methods to aid in the battle against glyphosate-resistant Palmer amaranth (Sosnoskie and Culpepper 2012).

Agricultural biotechnology companies are developing new technologies that will increase the portfolio of herbicide-resistant crops. Herbicides labeled for use in these crops may provide effective options for the control of Palmer amaranth with resistance to currently used herbicides. One such technology will be cotton resistant to preplant or topical applications of 2,4-D (Braxton et al. 2010). 2,4-dichlorophenoxyacetic acid was the first selective herbicide widely used in agriculture (Peterson 1967). Much research has quantified its effectiveness and limitations as a broadleaf herbicide in the decades since its discovery (Colby 1967; Migo et al. 1986; Triplett and Lytle 1972). Although 2,4-D is a member of the synthetic auxin family of herbicides, its site of action is currently unknown. Application of growth regulators, such as 2,4-D, induces an imbalance in phytohormone levels that causes epinasty of leaf stems and leaves and results in necrosis of meristematic tissue (Jursik et al. 2011). Synthetic auxins can be used for effective control of problematic broadleaves, such as common cocklebur (*Xanthium strumarium* L.), sicklepod (*Senna obtusifolia* L.), Palmer amaranth, and morningglory spp. (*Ipomoea* spp.) (Ferrell and Witt 2002; Lancaster et al. 2005; Norsworthy et al. 2008).

Cotton resistance to 2,4-D is conferred by the insertion of a gene that codes for an aryloxyalkanoate dioxygenase enzyme (Wright et al. 2010). Plants transformed to include this gene can metabolize certain auxin herbicides, including 2,4-D, to a nonlethal form (Richburg et al. 2012). The availability of cotton resistant to 2,4-D could increase POST herbicide options available to growers; especially when considering these 2,4-D–resistant cultivars will also be resistant to topical applications of glyphosate and glufosinate (Braxton et al. 2010). The objective of this study was to determine the most effective weed management system for the control of glyphosate-resistant Palmer amaranth in glyphosate, 2,4-D, and glufosinate-resistant cotton.

Materials and Methods

Two experiments were each conducted twice in Macon County, GA, during 2010 and 2011 for a total of four site-years. Macon County was chosen for each site because the population of Palmer amaranth is highly glyphosate resistant and because the crop is grown under dryland conditions usually offering extremely stressful environments (Culpepper et al. 2006). The aad-12 gene is the transformation conferring 2,4-D resistance in cotton that will be commercialized. However, because of limited seed availability, cotton with the aad-1 gene, which also confers 2,4-D resistance, was used in these studies (Dow Agro Sciences; Indianapolis, IN). The aad-1 gene has the ability to cleave members of the aryloxyphenoxy propionic acid family of grass-selective herbicides and is also able to inactivate 2,4-D, whereas the aad-12 gene is more effective at deactivating 2,4-D due to greater in vitro activity (Wright et al. 2010). Seed was planted across each study at 10 seed per meter of row spaced 91 cm apart with the use of a vacuum planter. Soil was conventionally prepared by rotary tiller early season with individual plots 3.6 m wide by 7.6 m in length having treatments replicated four times. The soil type was a Dothan loamy sand with 1.9 to 2.1% organic matter and a pH of 6.2 to 6.4.

Methods Specific to the 2,4-D Experiment. A factorial treatment design including three PRE herbicide options and three POST herbicide options was implemented. PRE options included no herbicide, pendimethalin (Prowl H_2O; BASF, Research Triangle Park, NC) at 1120 g ai ha^{-1}, or fomesafen (Reflex; Syngenta Crop Protection, Research Triangle Park, NC) at 280 g ai ha^{-1}. POST options were two sequential applications of 2,4-D (Weedar 64; NuFarm, Burr Ridge, IL) at 1,120 g ae ha^{-1}, 2,4-D at 1,120 g ha^{-1}plus glyphosate (Roundup WeatherMax; Monsanto, St. Louis, MO) at 840 g ae ha^{-1}, or 2,4-D at 1,120 g ha^{-1}plus glufosinate at 542 g ai ha^{-1} (Ignite; Bayer CropScience, Research Triangle Park, NC). Five additional treatments without PRE herbicide included sequential applications of (1) 2,4-D at 840 g ha^{-1}; (2) 2,4-D 840 g ha^{-1} plus glyphosate at 840 g ai ha^{-1}; (3) 2,4-D at 840 g ha^{-1} plus glufosinate 542 g ai ha^{-1}; (4) glyphosate alone at 840 g ai ha^{-1}, and (5) glufosinate alone at 542 g ai ha^{-1}. PRE applications were made the day of planting, POST 1 applications were made when Palmer amaranth reached 8 cm in height when no herbicide was applied PRE, and POST 2 applications were made 15 d after the POST 1 application. Location was planted on May 1 in 2010 and May 11 in 2011.

Methods Specific to the 2,4-D vs. 2,4-DB Experiment. A factorial treatment arrangement having three PRE herbicide options and five POST options was conducted. The three PRE options included no PRE, pendimethalin alone, or pendimethalin plus fomesafen. POST options included sequential applications of (1) 2,4-D at 840 g ha^{-1}, (2) 2,4-DB at 840 g ae ha^{-1}, (3) 2,4-D + glufosinate at 471 g ha^{-1}, (4) 2,4-DB + glufosinate at 471 g ha^{-1}, and (5) glufosinate alone at 471 g ha^{-1}. PRE applications were made the day of planting, POST 1 applications were made when Palmer amaranth reached 18 cm in height in plots not receiving a PRE herbicide, and POST 2 applications were made 15 d after the POST 1 application. Location was planted on May 1 in 2010 and June 16 in 2011.

Methods Common to Both Experiments. Layby-directed applications of diuron at 1,120 g ai ha^{-1} (Direx; DuPont Crop Protection, Wilmington, DE) plus MSMA at 1680 g ai ha^{-1} (MSMA 6 Plus; Drexel Chemical Company, Memphis, TN) plus Crop Oil at 2.3 L ha^{-1} (AGRI-DEX; Helena Chemical Company, Collierville, TN) were applied to all herbicide systems just prior to cotton canopy closure. Nontreated checks did not receive post-directed treatments. All applications were made with a CO_2-pressurized backpack sprayer equipped with 11002 DG flat-fan nozzles calibrated to deliver 140 L ha^{-1} at 165 kPa. No adjuvants were included with any PRE or POST application and a nontreated control was included for comparison. Insect control, fertilization, and defoliation practices were standard for dryland production in middle Georgia (Collins and Whitaker 2012).

Cotton plant heights were taken at layby and or at harvest by measuring the height of 20 plants per plot randomly. Cotton was harvested with a spindle picker modified for small-plot harvesting in November. Visual estimates of Palmer amaranth control were made prior to each herbicide application and at harvest using a visual scale of 0–100 with 0 = no control and 100 = complete plant death (Frans et al. 1986) Cotton stand was not influenced by treatments (data not shown) and seed cotton yield differences followed closely with late-season Palmer amaranth control, suggesting visual crop response had little impact on cotton yield. Palmer amaranth densities were obtained by counting all plants present between the two center rows of each plot following the layby application. There were no significant interactions between year and treatment, therefore data were combined over locations within experiments and analyzed with the use of PROC Mixed of SAS (SAS 9.2; SAS Institute, Cary, NC).

Site and replication were considered random effects, and treatments were considered fixed effects. Means were separated with the use of Fisher's LSD at $P > 0.05$. Treatments arranged as a factorial in the 2,4-D experimient were segregated and were analyzed as a factorial in PROC Mixed of SAS. This analysis did not alter the hierarchy of treatments compared to all treatments using a nonfactorial RCB design. Therefore comparisons were made with all treatments included.

Results and Discussion

2,4-D Experiment. Glyphosate applied sequentially with no PRE treatment provided no control at layby or harvest (Table 1). Sequential applications of 2,4-D, with the first application applied to 8-cm Palmer amaranth, provided only 62 to 66% control at layby and control was less than that observed with sequential glufosinate applications (79%). Control was poor at harvest with both the 2,4-D or glufosinate system after the layby was applied (62 to 79%), although the 2,4-D system with 1,120 g ha^{-1} was at least 11% more effective than when at the lower rate of 2,4-D or when glufosinate followed by a layby application was used. Mixing glyphosate with 2,4-D improved control beyond that observed with 2,4-D alone, but control was still only 79 to 86% at harvest depending on 2,4-D rate. Mixing glufosinate with 2,4-D controlled Palmer amaranth at least 95% throughout the season, both with and without a PRE treatment and regardless of 2,4-D rate used. The addition of pendimethalin or fomesafen PRE to sequential 2,4-D or glyphosate plus 2,4-D systems improved control to at least 93% at harvest with no differences between the two PRE options. Sequential applications of glufosinate plus 2,4-D following either PRE herbicide controlled Palmer amaranth 98 to 99% at harvest. Sequential applications of glyphosate plus 2,4-D following either PRE herbicide controlled Palmer amaranth 95 to 96% at harvest.

Table 1. Palmer amaranth control, cotton height, and seed cotton yield with POST systems including 2,4-D, glyphosate, and glufosinate.[a]

PRE herbicides			Palmer amaranth control			
Pendimethalin	Fomesafen	Sequential POST herbicides[b,c]	At layby	At harvest	Cotton height prior to layby	Seed cotton yield
g ha^{-1}	g ha^{-1}		%	%	cm	kg ha^{-1}
0	0	None	–[d]	–	18 e	0 g
0	0	2,4-D fb 2,4-D	66 ef	79 c	20 cde	960 cd
0	0	2,4-D + glyphosate fb 2,4-D + glyphosate	74 cd	86 bc	22 c	1,100 bc
0	0	2,4-D + glufosinate fb 2,4-D + glufosinate	97 a	95 a	27 b	1,360 a
1,120	0	2,4-D fb 2,4-D	86 b	93 ab	32 a	1,310 a
1,120	0	2,4-D + glyphosate fb 2,4-D + glyphosate	87 b	95 a	33 a	1,375 a
1,120	0	2,4-D + glufosinate fb 2,4-D + glufosinate	95 a	99 a	33 a	1,290 ab
0	280	2,4-D fb 2,4-D	89 b	95 a	34 a	1,355 a
0	280	2,4-D + glyphosate fb 2,4-D + glyphosate	98 a	96 a	35 a	1,350 a
0	280	2,4-D + glufosinate fb 2,4-D + glufosinate	99 a	98 a	34 a	1,350 a
0	0	2,4-D* fb 2,4-D*	62 f	68 d	19 de	715 e
0	0	Glyphosate fb glyphosate	0 g	0 f	20 cde	270 f
0	0	Glufosinate fb glufosinate	79 c	62 d	27 b	850 de
0	0	2,4-D* + glyphosate fb 2,4-D* + glyphosate	71 de	79 c	22 cd	980 cd
0	0	2,4-D* + glufosinate fb 2,4-D* + glufosinate	95 a	96 a	27 b	1,380 a

[a] Means within a column followed by the same letter are not significantly different according to Fisher's protected LSD test at $P < 0.05$. Data pooled over two locations. Diuron plus MSMA layby directed for all treatments except the nontreated control at time of canopy closure.

[b] Initial POST application made once Palmer amaranth reached 8 cm in height when no PRE was applied; sequential POST application made 15 d after the initial application. fb = followed by.

[c] 2,4-D applied at 1,120 g ae ha^{-1}, except when noted with an *, indicating 2,4-D applied at 840 g ha^{-1}. Glyphosate and glufosinate applied at 840 and 471 g ha^{-1}, respectively.

[d] Data not included in the analysis, as they were assigned values of 0.

Table 2. Palmer amaranth control, cotton height, and seed cotton yield with POST systems including 2,4-D, 2,4-DB, and glufosinate.[a]

PRE herbicides			Palmer amaranth control		Palmer amaranth density after layby	Cotton height after layby	Seed cotton yield
Pendimethalin	Fomesafen	Sequential POST herbicides[b,c]	At layby	At harvest			
g ha^{-1}	g ha^{-1}		%	%	plants ha^{-1}	cm	kg ha^{-1}
0	0	None	–[d]	–	139,000 a	27 f	70 g
0	0	2,4-D fb 2,4-D	54 e	46 e	11,900 d	62 c	590 e
0	0	2,4-DB fb 2,4-DB	41 e	16 f	72,200 b	43 e	300 f
0	0	2,4-D + glufosinate fb 2,4-D + glufosinate	91 abc	97 a	0 h	71 ab	1,480 ab
0	0	2,4-DB + glufosinate fb 2,4-DB + glufosinate	88 bc	87 b	0 h	71 ab	1,390 b
0	0	Glufosinate fb glufosinate	69 d	49 e	9,400 e	64 c	710 de
1,120	0	None	10 g	0 g	23,800 c	57 d	110 g
1,120	0	2,4-D fb 2,4-D	86 c	87 b	300 h	71 ab	1,400 b
1,120	0	2,4-DB fb 2,4-DB	67 d	58 d	4,400 g	62 c	780 d
1,120	0	2,4-D + glufosinate fb 2,4-D + glufosinate	97 ab	98 a	0 h	73 ab	1,490 ab
1,120	0	2,4-DB + glufosinate fb 2,4-DB + glufosinate	98 ab	95 ab	0 h	72 ab	1,570 a
1,120	0	Glufosinate fb glufosinate	92 abc	91 ab	300 h	76 a	1,320 bc
1,120	280	None	66 d	19 f	7,500 f	74 ab	440 f
1,120	280	2,4-D fb 2,4-D	92 abc	93 ab	0 h	70 b	1,490 ab
1,120	280	2,4-DB fb 2,4-DB	86 c	77 c	600 h	75 ab	1,240 c
1,120	280	2,4-D + glufosinate fb 2,4-D + glufosinate	99 a	99 a	0 h	70 b	1,460 ab
1,120	280	2,4-DB + glufosinate fb 2,4-DB + glufosinate	98 ab	99 a	0 h	72 ab	1,500 ab
1,120	280	Glufosinate fb glufosinate	99 a	96 ab	0 h	74 ab	1,410 b

[a] Means within a column followed by the same letter are not significantly different according to Fisher's protected LSD test at $P < 0.05$. Data pooled over two locations. Diuron plus MSMA layby directed for all treatments except the nontreated control at time of canopy closure.

[b] Initial POST application made once Palmer amaranth reached 18 cm in height when no PRE was applied; sequential POST application made 15 d after the initial application.

[c] Glyphosate, glufosinate, 2,4-D, and 2,4-DB applied at 840, 471, 840, and 840 g ha^{-1}, respectively. fb = followed by.

[d] Data not included in the analysis, as they were assigned values of 0.

Cotton plant heights were 22 to 48% taller in systems including a PRE herbicide compared to total POST systems at layby (Table 1). Early-season competition from Palmer amaranth has been well documented (Keeley and Thullen 1989; Morgan et al. 2001; Rowland et al. 1999) and even when making timely applications with effective POST herbicides, Palmer amaranth reduced cotton plant heights. Comparison of POST programs shows that cotton was 27 cm tall when glufosinate or glufosinate plus 2,4-D was applied and 18 to 22 cm when other herbicide systems were implemented.

Intense Palmer amaranth competition can reduce seed cotton yields and interfere with harvest efficiency (Fast et al. 2009; Morgan et al. 2001; Price et al. 2011). A Palmer amaranth population of 1 plant per 3 m of row can cause 13% yield loss; if the population increases to 10 plants per 3 m of row, yield losses can increase to 57% (Fast et al. 2009). Greatest yields were achieved when Palmer amaranth was most effectively controlled. Palmer amaranth control at harvest ranged from 93 to 99% when systems included a PRE herbicide or when glufosinate plus 2,4-D was the POST option; these systems yielded from 1,290 to 1,380 kg ha^{-1}. Total POST systems of 2,4-D at 840 g ha^{-1}, 2,4-D at 1120 g ha^{-1}, glufosinate, or glyphosate produced yields of 715, 960, 850, and 270 kg ha^{-1}, respectively.

2,4-D and 2,4-DB Experiment. Delaying initial POST herbicide applications until Palmer amaranth reached 18 cm created a challenging weed control situation (Table 2). At layby, sequential 2,4-D (54%) or glufosinate (69%) programs provided unacceptable control and the addition of the layby had little effect with these two systems controlling Palmer amaranth only 46 to 49% at harvest. The

2,4-DB program was 13 and 30% less effective than comparative 2,4-D systems at layby or harvest, respectively. When applied in a timely manner, 2,4-DB is more effective than observed in this experiment, but Palmer amaranth control is still often not adequate (Grichar 1997). Mixtures of glufosinate and 2,4-D or 2,4-DB were more effective than any herbicide applied alone with control ranging from 88 to 91% at layby and 87 to 97% at harvest. The addition of pendimethalin PRE improved late-season control of sequential 2,4-D (87%), 2,4-DB (58%), and glufosinate (91%) systems, but did not improve control when POST options included an auxin mixed with glufosinate (95 to 98%). Fomesafen is effective in controlling Palmer amaranth (Everman et al., 2009), but the addition of fomesafen to pendimethalin PRE only improved control of the sequential 2,4-DB system.

Palmer amaranth densities following the layby were 139,000 plants ha^{-1} in the nontreated control. Systems including an auxin plus glufosinate POST and the layby eliminated all Palmer amaranth plants, regardless of presence of a PRE herbicide. The only other two systems that eliminated Palmer amaranth populations included pendimethalin plus fomesafen PRE followed by sequential 2,4-D or glufosinate applications, and the layby.

Cotton heights were reflective of Palmer amaranth control. Cotton was at least 70 cm tall after the layby with all programs, including glufosinate plus an auxin POST, fomesafen PRE, or pendimethalin plus 2,4-D POST. Total POST programs with 2,4-D, 2,4-DB, or glufosinate resulted in shorter cotton ranging between 43 and 62 cm in height. Seed cotton yields were also reflective of Palmer amaranth populations present after the layby. Seed cotton yields of 1,390 to 1,570 kg ha^{-1} were recorded from all systems including 2,4-D or 2,4-DB plus glufosinate and the layby, with or without a PRE herbicide. Other systems with similar yields exceeding 1,390 kg ha^{-1} included pendimethalin or pendimethalin plus fomesafen followed by sequential 2,4-D or glufosinate applications and the layby. Direct comparison of auxin programs with and without PRE herbicides shows that yields were always higher with the 2,4-D–alone system as compared to the 2,4-DB–alone system.

Cotton technology with resistance to glyphosate, 2,4-D and glufosinate will improve grower flexibility and postemergence management of Palmer amaranth. Numerous effective systems can be developed with this technology. In these studies, tank mixtures of glufosinate plus 2,4-D or systems containing both 2,4-D and glufosinate were among the most effective for controlling emerged Palmer amaranth. Additionally, at-plant residual herbicides allow for consistent performance of all 2,4-D systems when compared to current systems (Monks et al. 2012; Sosnoskie et al. 2011; Sosnoskie and Culpepper 2012).

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