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WEED SCIENCE

Weed Response to 2,4-D, 2,4-DB, and Dicamba Applied Alone or with Glufosinate

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ABSTRACT

Cotton tolerant of 2,4-D, glufosinate, and glyphosate or dicamba, glufosinate, and glyphosate is in development. This technology will give growers additional tools to manage glyphosate-resistant weeds. A field experiment was conducted across six environments in Georgia, North Carolina, and Tennessee to determine the response of 13- to 20-cm weeds to 2,4-D, 2,4-DB, and dicamba applied alone or mixed with glufosinate. Palmer amaranth (*Amaranthus palmeri* S. Wats) was controlled 59 to 78%, 68 to 80%, and 59 to 83% by 2,4-DB dimethylamine (560-1120 g ae ha^{-1}), 2,4-D dimethylamine (530-1060 g a.e. ha^{-1}), and dicamba diglycolamine (280-1120 g ae ha^{-1}), respectively, and 74% by glufosinate ammonium (430 g ae ha^{-1}). Control was improved (89-97%) with all auxin/glufosinate mixtures when compared to respective herbicides alone. Glufosinate controlled Benghal dayflower (*Commelina benghalensis* L.) only 68%; 2,4-D at 530 g ha^{-1} and dicamba at 1120 g ha^{-1} controlled this weed at least 90%. Combinations of glufosinate and auxin herbicides were beneficial when control by auxin herbicides was 90% or less. Carpetweed (*Mollugo verticillata* L.) control by auxin herbicides ranged from 50 to 66%; glufosinate alone or in mixtures completely controlled carpetweed. All treatments completely controlled morningglory (*Ipomoea* spp.). Auxin herbicides had no activity on grasses. Texas millet (*Panicum texanum* [Buckl.] R. Webster) and broadleaf signalgrass (*Brachiaria platyphylla* [Nash] R. Webster) were controlled 89 to 90% by glufosinate alone. Both 2,4-D and 2,4-DB mixed with glufosinate reduced Texas millet control, and 2,4-D reduced broadleaf signalgrass control.

Glyphosate-resistant Palmer amaranth (*Amaranthus palmeri* S. Wats) has drastically changed agronomic crop production throughout the southeastern U.S., most notably cotton production (Sosnoskie and Culpepper, 2012; Webster and Sosnoskie, 2010). Ninety-two percent of Georgia cotton growers hand-weeded 54% of their crop, spending an average of $63.50 per hand-weeded hectare during 2010 (Sosnoskie and Culpepper, 2012). Hand-weeding is a secondary line of defense against this pest as these same growers apply more than $150 ha^{-1} in herbicides with applications beginning at burndown and continuing through cotton canopy closure. Additionally, these growers have reduced conservation tillage by 7%, increased cultivation to 43% of the hectares, and increased both the use of moldboard plows (100,000 ha during 2009 and 2010) and the use of secondary preplant tillage implements to incorporate herbicides (100,000 ha during 2010) in conventionally tilled systems (Culpepper et al., 2010; Price et al., 2011; Sosnoskie and Culpepper, 2012).

Effective control of Palmer amaranth in cotton has been achieved with glufosinate-based systems (Culpepper et al., 2009; Everman et al., 2007; Gardner et al., 2006; Whitaker et al., 2011). Glufosinate must be applied to small Palmer amaranth for consistently effective control (Coetzer et al., 2002; Culpepper et al., 2010). Palmer amaranth grows rapidly (Horak and Loughin, 2000) and growers are often unable to make timely applications. Another herbicide mixed with glufosinate might improve control of larger weeds. Herbicides that could potentially be mixed with glufosinate applied postemergence include MSMA, pyrithiobac, trifloxysulfuron, and fluometuron. MSMA has poor activity on Palmer amaranth, especially at rates that can be applied overtop of cotton (Culpepper, 2012). Moreover, combinations of MSMA plus glufosinate might be antagonistic (Koger et al., 2007). The ALS-inhibiting herbicides

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pyrithiobac and trifloxysulfuron can control Palmer amaranth (Branson et al., 2005; Culpepper and York, 1997). However, Palmer amaranth biotypes resistant to ALS-inhibiting herbicides are widespread across the Mid-South and Southeast (Heap, 2012; Wise et al., 2009). Fluometuron mixed with glufosinate has improved control of larger Palmer amaranth (Barnett et al., 2011), but postemergence (topical) application of fluometuron has been discouraged because it injures cotton, delays maturity, and sometimes reduces yield (Byrd and York, 1987; Snipes and Byrd, 1994).

Transgenic cotton resistant to 2,4-D is being developed (Braxton et al., 2010). The traits for resistance to these auxin herbicides will be stacked with traits conferring resistance to both glufosinate and glyphosate. Auxin herbicides are effective on a number of broadleaf weeds commonly infesting cotton (Green and Owen, 2011; Mueller et al., 2005), and they will be recommended in combination with glufosinate. It is important that Extension personnel and other advisors better understand the response of weeds to these herbicide mixtures.

MATERIALS AND METHODS

The experiment was conducted in 2009 at Macon, Tift, and Colquitt counties in Georgia. Three experiments, separated by planting date, were conducted at the Macon County location. The experiment also was conducted in 2010 at Worth County, GA, Shelby County, TN, and Edgecombe County, NC. All sites were fallow fields with naturally occurring weed populations being evaluated (Table 1). Plot sizes were 1.8 by 7.6 m in Georgia, 1.5 by 6.1 m in Tennessee, and 3 by 6.1 m in North Carolina. Soils in Georgia and North Carolina were loamy sands or sandy loams, whereas the soil in Tennessee a silt loam. The experimental design was a randomized complete block with four replications of each treatment. Treatments consisted of a factorial arrangement of two rates of glufosinate by 10 auxin herbicide and rate combinations. Glufosinate ammonium salt (Ignite 280 SL Herbicide, Bayer CropScience LP, Research Triangle Park, NC) was applied at 0 and 430 g ae ha^{-1}. The auxin herbicide and rate combinations included the following: no auxin herbicide; the dimethylamine salt of 2,4-DB (Agri Star® Butyrac® 200 Broadleaf Herbicide, Albaugh, Inc., Ankeny, IA) at 560, 840, and 1120 g ae ha^{-1}; the dimethylamine salt of 2,4-D (Nufarm Weedar® 64, Nufarm, Inc., Burr Ridge, IL) at 530, 800, and 1060 g ae ha^{-1}; and the diglycolamine salt of dicamba (Clarity® Herbicide, BASF Corp., Research Triangle Park, NC) at 280, 560, and 1120 g ae ha^{-1}. Herbicides were applied to weeds at the sizes indicated in Table 1 using CO_2-pressurized backpack sprayers calibrated to deliver 140 L/ha at 165 kPa in Georgia and North Carolina or 140 L/ha at 207 kPa in Tennessee. Nozzles included DG11002 TeeJet® Drift Guard Flat Fan Spray Tips (TeeJet Technologies, Wheaton, IL) with 45.7-cm nozzle spacing in Georgia and North Carolina and TP8002 TeeJet® Flat Spray Tips (TeeJet Technologies, Wheaton, IL) with 50.8-cm nozzle spacing in Tennessee.

Table1. Weed size[z] and density at time of herbicide application

Location	Year	Weeds Present	Weed size at application	Weed density at application
			cm	plants m^{-2}
Macon County, GA[Y]	2009	Palmer amaranth	15-20	125
Tift County, GA	2009	Palmer amaranth	18-25	7
		Carpetweed	13-18	4
Colquitt County, GA	2009	Pitted morningglory	18-23	4
		Benghal dayflower	15-20	22
		Broadleaf signalgrass	20	12
Shelby County, TN	2010	Palmer amaranth	20	65
Worth County, GA	2010	Texas millet	15-20	18
		Entireleaf morningglory	15-20	10
Edgecombe County, NC	2010	Broadleaf signalgrass	15 cm	60

[z] Size refers to height of Palmer amaranth, Benghal dayflower, broadleaf signalgrass, and Texas millet, diameter of carpetweed, and runner length of pitted morningglory and entireleaf morningglory.

[y] Three trials were conducted at the Macon site, each with Palmer amaranth at similar densities.

Weed control was estimated visually at 10, 20, and 30 d after herbicide application using a scale of 0 to 100, where 0 = no control and 100 = complete control (Frans et al., 1986). With weed responses being consistent across evaluation dates, only the 20-d evaluation is reported. Data were transformed to improve normality and homogeneity of variance and then analyzed using PROC Mixed of SAS (version 9.1; SAS Institute, Inc., Cary, NC). Site and replication were considered random effects, whereas treatments were considered fixed effects. When significant differences were noted, interaction means were present and post-hoc pair-wise comparisons were made using Tukey's HSD at $P \leq 0.05$ to specifically compare auxin plus glufosinate mixtures to the respective auxin applied alone. Nontransformed comparisons are reported.

RESULTS AND DISCUSSION

Palmer Amaranth. Glufosinate applied alone controlled Palmer amaranth only 74% (Table 2), a level of control expected when treating 20-cm tall plants (Coetzer et al., 2002). 2,4-D controlled Palmer amaranth 68, 79, and 80% when applied at 530, 800, and 1060 g ha^{-1} respectively. Control by 2,4-DB at 840 and and 1120 g ha^{-1} and dicamba at 560 and 1120 g ha^{-1} was similar to control by 2,4-D at 800 and 1060 g ha^{-1}. At the lowest application rate of 530 g ha^{-1}, 2,4-D was 9% more effective than 2,4-DB at 560 g ha^{-1} or dicamba at 280 g ha^{-1}.

None of the three auxin herbicides, regardless of application rate, nor glufosinate controlled Palmer amaranth greater than 80% (Table 2). Palmer amaranth can be present at densities of 100 or more plants m^{-2} early in the season in nontreated cotton (Culpepper et al., 2006; Whitaker et al., 2011), and Palmer amaranth is competitive with cotton (Morgan et al., 2001; Rowland et al., 1999). In addition to high plant densities of Palmer amaranth, the competitiveness of the weed dictates the need for near perfect control.

We emphasize that these results are from single applications to weeds larger than the optimal size for treatment. Greater control would be expected if the Palmer amaranth had been smaller at application (Edwards et al., 2012; Voth et al., 2012). Similarly, greater control would be expected with a follow-up application of any of the four herbicides (Siebert et al., 2011). By intentionally delaying application until Palmer amaranth was 15 to 20 cm tall, we were better able to determine differences in efficacy of the herbicides and the effect of mixing auxin herbicides with glufosinate.

Table 2. Control of Palmer amaranth, Benghal dayflower, and carpetweed 20 days after application of 2,4-DB, 2,4-D, and dicamba alone and mixed with glufosinate[z]

Auxin herbicide	Auxin herbicide rate	Palmer amaranth		Benghal dayflower		Carpetweed	
		No glufosinate	+ glufosinate[y]	No glufosinate	+ glufosinate	No glufosinate	+ glufosinate
	g ha^{-1}	%					
No Auxin	**---**	**--**	**74**	**--**	**68**	**--**	**100**
2,4-DB	**560**	**59**	**92*[w]**	**60**	**78***	**59**	**100***
2,4-DB	**840**	**71**	**93***	**72**	**83***	**50**	**100***
2,4-DB	**1120**	**78**	**95***	**71**	**80***	**55**	**100***
2,4-D	**532**	**68**	**90***	**90**	**98***	**66**	**100***
2,4-D	**798**	**79**	**93***	**99**	**98**	**59**	**100***
2,4-D	**1064**	**80**	**97***	**98**	**99**	**63**	**100***
Dicamba	**280**	**59**	**89***	**69**	**97***	**55**	**100***
Dicamba	**560**	**76**	**92***	**84**	**94***	**58**	**100***
Dicamba	**1120**	**83**	**94***	**94**	**94**	**60**	**100***
LSD (0.05)		**9**		**9**		**13**	

[z] **Results for Palmer amaranth, tropical spiderwort, and carpetweed combined over 6, 1, and 1 locations, respectfully.**

[y] **Glufosinate applied 431 g ha^{-1}.**

[w] **Means followed by an asterisk (*) indicate the mixture of glufosinate plus auxin herbicide was more effective than the respective auxin herbicide and rate applied alone using Tukey's HSD at $P \leq 0.05$ post-hoc pair-wise comparisons.**

Compared with 74% control by glufosinate alone, auxin herbicides mixed with glufosinate increased Palmer amaranth control to 89 to 97% (Table 2). Control by all glufosinate/auxin combinations was greater than control by the auxin herbicides alone or glufosinate alone. Improved control of Palmer amaranth (Voth et al., 2012; York et al., 2012) and other weeds (Chahal and Johnson, 2012; Steckel et al., 2006) with mixtures of glufosinate and auxin herbicides has been observed in other studies.

Benghal Dayflower. Control of Benghal dayflower (*Commelina benghalensis* L.) in this study was as expected (Protsko, 2011a, 2011b). 2,4-D controlled Benghal dayflower 90 to 99% and was more effective than 2,4-DB or glufosinate (Table 2). Dicamba was as effective as 2,4-D when applied at 560 and 1120 g ha^{-1}. Glufosinate applied alone controlled Benghal dayflower only 68%, but mixtures of glufosinate plus either 2,4-D or dicamba increased control to 94 to 99%. Control by mixtures of glufosinate plus 2,4-DB was greater than control by 2,4-DB or glufosinate alone, but combinations of glufosinate plus 2,4-DB were less effective than mixtures of glufosinate plus either 2,4-D or dicamba.

Carpetweed. Auxin herbicides controlled carpetweed (*Mollugo verticillata* L.) only 50 to 66% regardless of product or rate used (Table 2). Glufosinate completely controlled carpetweed when applied alone or in combination with any of the auxin herbicides.

Morningglory. Regardless of rate, glufosinate and each auxin herbicide controlled morningglory species (*Ipomoea* spp.) completely (Table 3). Complete control also was obtained with all glufosinate plus auxin herbicide combinations. Auxin herbicides and glufosinate are expected to be effective on *Ipomoea* morningglory species (Corbett et al., 2004; Prostko, 2011a, 2011b).

Broadleaf Signalgrass and Texas Millet. Auxin herbicides did not control the two annual grass species: Texas millet (*Panicum texanum* [Buckl.] R. Webster) and broadleaf signalgrass (*Brachiaria platyphylla* [Nash] R. Webster) (Table 3). However, glufosinate controlled these grasses 89 to 90%. Texas millet control by mixtures of glufosinate plus dicamba was similar to control by glufosinate alone. In contrast, both 2,4-D and 2,4-DB mixed with glufosinate reduced Texas millet control 9 to 21%. Neither dicamba nor 2,4-DB mixed with glufosinate adversely affected broadleaf signalgrass control by glufosinate, but control with glufosinate plus 2,4-D was less than control by glufosinate alone in two of the three combinations.

Table 3. Control of morningglory, broadleaf signalgrass, and Texas millet 20 days after application of 2,4-DB, 2,4-D, and dicamba alone and mixed with glufosinate[z]

Auxin herbicide	Auxin herbicide rate	Morningglory[y]		Broadleaf signalgrass		Texas millet	
		No glufosinate	+ glufosinate[x]	No glufosinate	+ glufosinate	No glufosinate	+ glufosinate
	g ha^{-1}	%					
No Auxin	---	--	100	--	89	--	90*
2,4-DB	560	100	100	0	95*[w]	0	78*
2,4-DB	840	100	100	0	95*	0	70*
2,4-DB	1120	100	100	0	90*	0	69*
2,4-D	532	100	100	0	81*	0	81*
2,4-D	798	100	100	0	85*	0	81*
2,4-D	1064	100	100	0	82*	0	70*
Dicamba	280	100	100	0	90*	0	91*
Dicamba	560	100	100	0	89*	0	94*
Dicamba	1120	100	100	0	84*	0	95*
LSD (0.05)		NS		7		9	

[z] Results for morningglory, broadleaf signalgrass, and Texas millet combined over 2, 2, and 1 locations, respectfully.

[y] Results for morningglory combined over one location with pitted morningglory and one with entireleaf morningglory..

[x] Glufosinate applied 431 g ha^{-1}.

[w] Means followed by an asterisk (*) indicate the mixture of glufosinate plus auxin herbicide was more effective than the respective auxin herbicide and rate applied alone using Tukey's HSD at $P \leq 0.05$ post hoc pair-wise comparisons.

Previously published research shows that 2,4-D and 2,4-DB can reduce control of grassy weeds when these auxins are mixed with cyclohexanedione and aryloxyphenoxy propionate herbicides (Blackshaw et al., 2006; Mueller et al., 1989; York et al., 1993). Mixtures of glyphosate plus auxin herbicides usually have been additive, or sometimes synergistic, on dicot species (Chahal and Johnson, 2012; Culpepper et al., 2001; Jordan et al., 1997; Wehtje and Walker, 1997). Varying results have been reported with mixtures of glyphosate plus auxin herbicides applied to grassy weeds. 2,4-DB mixed with glyphosate had no effect on control of large crabgrass (Culpepper et al., 2001) or barnyardgrass [*Echinochloa crus-galli* (L.) Beauv.] (Jordan et al., 1997). 2,4-D mixed with glyphosate reduced control of johnsongrass, quackgrass, wheat, barley, and wild oat (O'Donavan and O'Sullivan, 1982). Dicamba and 2,4-D mixed with glyphosate reduced control of johnsongrass (Flint and Barrett, 1989).

Research with mixtures of auxin herbicides and glufosinate is much more limited. Dicamba and 2,4-D mixed with glufosinate generally have increased control of horseweed [*Conyza canadensis* (L.) Cronq.], common lambsquarters (*Chenopodium album* L.), and Palmer amaranth (Chahal and Johnson, 2012; Steckel et al., 2006; Voth et al., 2012; York et al., 2012). However, Botha et al. (2012) reported antagonism with dicamba plus reduced rates of glufosinate applied to Palmer amaranth. No results have been published on grass weed control by mixtures of glufosinate plus 2,4-D, 2,4-DB, or dicamba. However, quinclorac and triclopyr are auxin herbicides, and Lanclos et al. (2002) reported antagonism on barnyardgrass and broadleaf signalgrass with mixtures of glufosinate plus quinclorac or triclopyr.

New technologies allowing topical application of auxin herbicides to cotton will provide additional tools desperately needed by cotton growers to manage glyphosate-resistant weeds. However, auxin herbicides applied alone likely will not adequately control glyphosate-resistant Palmer amaranth. Glufosinate/auxin combinations will more effectively control Palmer amaranth and a broader spectrum of dicot weeds as compared to either of these chemistries applied alone. Additionally, the use of glufosinate/auxin combinations can potentially extend the useful life of both herbicides and technologies. Our results with glufosinate/auxin combinations on Texas millet and broadleaf signalgrass indicate the need for more research to better understand potential problems with the mixtures.

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