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WEED SCIENCE

Cotton Tolerance to Fomesafen Applied Preemergence

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ABSTRACT

Field studies were conducted in Georgia, North Carolina, South Carolina, Tennessee, and Virginia during 2006 to investigate tolerance of cotton to fomesafen applied preemergence (PRE). Fomesafen at seven rates, and two standard herbicides, pyrithiobac and fluometuron, were applied PRE to cotton in a weed-free environment. Cotton tolerance to fomesafen was directly related to rainfall that occurred from planting through cotton emergence. No injury was detected in South Carolina or Tennessee, but heavy rainfalls prior to cotton emergence in Georgia led to 3 to 9% early season visible stunting by fomesafen at 140 to 420 g a.i. ha^{-1} and 11 to 15% stunting by fomesafen at 560 and 840 g ha^{-1}. In North Carolina and Virginia, rainfall during cotton emergence led to early season cotton necrosis ranging from 4 to 16% with fomesafen at 140 to 350 g ha^{-1} and 12 to 45% by fomesafen at 420 to 840 g ha^{-1}. Early season injury by fomesafen at 280 g ha^{-1} (recommended use rate) was equal to or less than pyrithiobac or fluometuron at 4 of 5 locations. Mid-season injury was 10% or less at all locations with fomesafen at 490 g ha^{-1} or less. Plant heights were reduced 11 to 29% in Georgia and North Carolina when fomesafen was applied at rates greater than 420 g ha^{-1}. In Tennessee, heights were reduced 8% with fomesafen at 560 g ha^{-1}. Compared to the non-treated control, plant stands were reduced 23 to 28% only in North Carolina when fomesafen rates exceeded 350 g ha^{-1}. Lint yields followed trends in plant stand, with yield being reduced 23 to 25% by fomesafen at 560 to 840 g ha^{-1} only in North Carolina. Cotton fiber quality and cotton fruit distribution or number of fruit set, were not adversely affected by herbicides.

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INTRODUCTION

Glyphosate-resistant (GR) cotton cultivars are planted on greater than 97% of the cotton hectares throughout the southeastern U.S. Glyphosate-based weed management programs used with this technology have revolutionized weed management. Prior to the adoption of GR cotton, traditional cotton weed control programs often consisted of combinations of preplant incorporated, preemergence (PRE), postemergence (POST), and postemergence-directed applications of herbicides (Wilcut et al., 1995). Glyphosate-based weed management programs offer growers more application flexibility, greater broad-spectrum weed control, reductions in time and labor inputs, and less complicated weed management strategies (Askew et al., 2002; Culpepper and York, 1998; Young, 2006), thus, glyphosate-based programs rapidly replaced traditional herbicide systems.

Widespread planting of GR cotton and extensive use of glyphosate have placed intensive selection pressure on weed populations. Resistance to glyphosate in horseweed (*Conyza canadensis* [L.] Cronq.), common ragweed (*Ambrosia artemisiifolia* L.), giant ragweed (*Ambrosia trifida* L.), Italian ryegrass (*Lolium multiflorum*), and Palmer amaranth (*Amaranthus palmeri* S. Wats) has been confirmed in the southeastern U.S. (Brewer and Oliver, 2009; Culpepper et al., 2006; Heap, I., 2011; Main et al., 2004; Nandula et al., 2007; Norsworthy et al., 2010; VanGessel, 2001). Although GR weeds are becoming common and problematic overall, GR Palmer amaranth has forever changed cotton weed management and is currently the greatest pest management challenge for cotton producers (Culpepper and Steckel, 2010; MacRae et al., 2008; Nichols et al., 2009). Pyrithiobac, an acetolactate synthase (ALS)-inhibiting herbicide, applied POST will control small Palmer amaranth (Branson et al., 2005; Corbett et al., 2004). Unfortunately, Palmer amaranth resistant to ALS-inhibiting herbicides is also common across the southeastern U.S. and, in many cases the weed has multiple resistance to both glyphosate and ALS-inhibiting herbicides (Sosnoskie et al., 2009; Whitaker, 2009; Wise et al., 2009). In fields where Palmer amaranth is resistant to both glyphosate and ALS-inhibiting herbicides, no topical herbicide option exists for GR cotton producers. Selection of residual herbicides applied at planting has become one of the most important decisions cotton growers make when trying to control Palmer amaranth. Fomesafen has been one of the more effective residual herbicides for the control of GR and GR plus ALS-resistant Palmer amaranth (Gardner et al., 2006; Kichler et al., 2008, 2009, 2010; Marshall, 2009; Whitaker, 2009).

Fomesafen, a diphenylether herbicide that inhibits protoporphyrogen oxidase (PPO), was registered in 2006 for use in cotton at rates of 280 to 420 g ha^{-1} for PRE weed control in cotton planted in course-textured soils (Anonymous, 2011). Previous research has indicated cotton tolerance to fomesafen applied PRE (Baumann et al., 1998; Gardner et al., 2006; Troxler et al., 2002). However, data describing the activity of PPO herbicides, including fomesafen, in varying soil types and moisture regimes is limited. Reiling et al. (2006) reported that soybean (*Glycine max* L.) injury from PRE-applied sulfentrazone, another PPO herbicide, increased when soil pH rose from 5.5 to 7.5. Taylor-Lovell et al. (2001) reported that sulfentrazone and flumioxazin caused greater levels of soybean injury under wet, low organic matter soil conditions. These studies suggest that the solubility of PRE-applied PPO herbicides in the soil may impact crop development. With limited reports of cotton response to fomesafen PRE, and with the wide-spread use of this herbicide on cotton, it is critical to examine cotton response to fomesafen in numerous environments as crop injury may be influenced by soil characteristics and soil moisture.

MATERIAL AND METHODS

An experiment to determine tolerance of cotton to fomesafen applied PRE was conducted at five locations across five states in the southeastern U.S. during 2006. Locations, soil descriptions, planting dates, and harvest dates are listed in Table 1. Cultivars planted included DP 555 BG/RR (Monsanto Co., St. Louis, MO) in Georgia, DP 117 B2RF (Monsanto Co., St. Louis, MO) in South Carolina and Virginia, ST 4554B2RF (Bayer CropScience, Research Triangle Park, NC) in North Carolina, and ST 4357B2RF (Bayer CropScience, Research Triangle Park, NC) in Tennessee. Conventional tillage production systems were implemented at all locations except in Tennessee where a no-tillage system planting into weedy stubble was implemented. All other production practices other than weed control followed University recommendations standard for each region.

The experimental design was a randomized complete block with treatments replicated six times in North Carolina and four times at the other locations. Plots were four rows by 9.1 m, with row spacing of 97 cm in South Carolina and Tennessee and 91 cm at the other locations. Treatments at all locations included fomesafen (Syngenta Crop Protection, Greensboro, NC) at 140, 280, 350, 420, 490, 560, and 840 g ha^{-1}, fluometuron (Makhteshim Agan of North America, Raleigh, NC) at 1120 g a.i. ha^{-1}, and pyrithiobac (DuPont Crop Protection, Wilmington, DE) at 60 g a.i. ha^{-1} applied PRE. Herbicides were applied in a spray volume of 140 L ha^{-1} within 4 h after planting using a CO_2-pressurized tractor-mounted sprayer in Virginia or CO_2-pressurized backpack sprayers in the other states. Experiments were conducted in areas free of glyphosate-resistant weeds and maintained weed-free by applying glyphosate (Roundup WeatherMAX, Monsanto Co., St. Louis, MO) at 0.8 kg a.e. ha^{-1}

Table 1. Trial location and agronomic information.

Location	Planting date	Harvest date	Soil series	Soil texture	Soil pH	Soil OM (%)
Ty Ty, GA	24 April	5 September	Tifton[z]	Loamy Sand	6.4	0.8
Rocky Mount, NC	2 May	31 October	Marlboro[y]	Loamy Sand	5.3	0.7
Florence, SC	24 April	20 September	Norfolk[x]	Loamy Sand	5.9	0.8
Jackson, TN	17 April	17 September	Lexington[w]	Silt Loam	6.0	1.5
Suffolk, VA	2 May	6 November	Norfolk	Loamy Sand	6.3	0.9

[z] Fine-loamy, kaolinitic, thermic Plinthic Kandiudults.

[y] Fine, kaolinitic, thermic Typic Paleudults.

[x] Fine, kaolinitic, thermic Typic Kandiudults.

[w] Fine-silty, mixed, active, thermic Ultic Hapludalfs.

topically when cotton was in the 1- and 5-leaf stages of growth followed by glyphosate directed to cotton in the 12- to 15-leaf stage.

Evaluations of cotton response at all locations included early season visible injury from 14 to 28 d after cotton emergence (DAE), mid-season injury from 60 to 75 DAE, stand counts 21 to 35 DAE, plant height 21 to 60 DAE, and lint cotton yield. Visible cotton injury was recorded on a scale of 0 to 100, where 0 indicates no cotton injury (chlorosis, necrosis, crop stunting) and 100 indicates cotton death (Frans et al., 1986). Plant stands were recorded from the total length of the center two rows of each plot and averaged over two rows while plant heights were recorded from 10 consecutive plants per plot. The center two rows of each plot were harvested using spindle pickers modified for small-plot harvesting. A sample of mechanically harvested seed cotton was collected from each plot and used to determine lint percentage and fiber quality (fiber quality measured in North Carolina and South Carolina only). Seed cotton was ginned on a laboratory gin without lint cleaning. Cotton grades are not presented as they would not be representative of cotton ginned commercially. However, fiber upper half mean length, fiber length uniformity index, fiber strength, and micronaire were determined by high volume instrumentation testing (Sasser, 1981).

Additional measurements after defoliation and prior to harvest in South Carolina and Tennessee included total number of main-stem nodes, number of sympodia with one or more bolls (hereafter referred to as effective sympodia), node number of the first effective sympodium, total number of bolls and aborted positions on sympodial branches, and number of bolls on monopodial branches on 10 consecutive plants per plot. Total bolls and aborted positions on sympodial branches were summed for total sympodial fruiting sites. Sympodial and monopodial bolls were summed for presentation and were compared as number per m^2. Percent sympodial boll retention was calculated from the total number of sympodial bolls and the total number of sympodial fruiting sites. Percent first position boll retention on sympodial branches was similarly calculated from the total number of first position bolls and the total number of first position fruiting sites.

Data were subjected to analysis of variance using the PROC MIXED procedure of SAS (ver. 9.2; SAS Institute; Cary, NC). Arcsine square root transformation of percentage data did not improve homogeneity of variance; therefore, non-transformed data were used in the analysis. Means were separated using Fishers Protected LSD test at the 0.05 significance level.

RESULTS AND DISCUSSION

Analysis of variance indicated a treatment by location interaction for cotton injury, cotton stand, cotton height, and lint yield. Data were analyzed by location for each parameter.

Cotton injury, stand, and height. In South Carolina and Tennessee, 2.7 to 4.7 cm of rainfall were received in the first 4 d after planting and before cotton emergence (Table 2). No visible cotton injury was observed at either of these locations (Table 3). Herbicide treatments also did not impact plant stand at either location or plant height in South Carolina (Tables 4 and 5). Pyrithiobac and fomesafen at 560 g ha^{-1} reduced plant height 8 to 11% in Tennessee.

The Georgia location was irrigated with 1.3 cm of water after planting and applying treatments, and a single 4-cm rainfall event in a 30-min period occurred 2 d later prior to cotton emergence (Table 2). Herbicide treatments did not cause necrosis or chlorosis, but fomesafen at 280 to 490 g ha^{-1} visibly stunted cotton 8 to 9%, while fomesafen at 560 and 840 g ha^{-1} stunted cotton 11 to 15% early in the season (Table 3). Although cotton stunting was detected with fomesafen, the extent of cotton stunting was no greater than that caused by pyrithiobac (13%). Stunting by fomesafen at the registered use rates of 280 to 420 g ha^{-1} was only 4 to 5 percentage points greater than stunting by fluometuron. The heavy rainfall on a nearly saturated low organic matter, loamy sand soil likely moved the herbicide into the cotton root zone, leading to stunted plant growth (Mills and Simmons, 1998; Spadotto, 2002; Weber et al., 1993). Cotton stands in Georgia were not impacted by herbicide treatments (Table 4), but plant heights 27 d after planting were reduced 24 to 29% by fomesafen at 560 and 840 g ha^{-1} and 24% by pyrithiobac (Table 5). By 10 wk after planting, no visible stunting was observed (Table 3). The overall rainfall amount during the first 5 d after planting for Georgia and Tennessee was similar (Table 2). Less injury in Tennessee, compared with Georgia, may have been due to surface residue in the no-tillage production system in Tennessee, greater soil organic matter in Tennessee (Table 1), and the intensity of the rainfall 2 d after planting in Georgia. These factors likely caused more herbicide to be moved into the cotton root zone in Georgia.

Table 2. Rainfall and irrigation during first 14 d after fomesafen PRE application.

Days after fomesafen application	Rainfall and irrigation (cm)				
	Georgia	North Carolina	South Carolina	Tennessee	Virginia
0	1.30[z]	0.00	0.00	0.00	0.00
1	0.00	0.00	0.00	0.00	0.51
2	4.00	0.00	1.75	0.00	0.00
3	0.00	0.03	0.94	1.24	1.02
4	0.00	0.99	0.00	3.45	0.23
5	0.00	4.11	0.00	0.00	1.55
6	0.00	0.18	0.00	0.00	1.30
7	0.00	0.00	0.00	0.00	0.00
8	0.00	0.00	0.00	0.46	0.00
9	0.00	0.23	0.00	2.24	0.84
10	0.00	0.00	0.00	0.00	0.00
11	1.60	0.00	5.72	0.03	0.00
12	0.00	2.77	0.00	0.05	0.84
13	0.84	0.28	2.74	1.91	0.30
14	2.03	0.00	0.00	0.00	0.00
Total	9.77	8.59	11.15	9.38	6.59

[z] Irrigation.

Table 3. Cotton injury from fomesafen applied PRE.

Herbicides	Application rate (g ha^{-1})	Injury (%)									
		Georgia		North Carolina		South Carolina		Tennessee		Virginia	
		Early[z]	Mid[y]	Early	Mid	Early	Mid	Early	Mid	Early	Mid
Untreated	--	0	0	0	0	0	0	0	0	0	0
Fomesafen	140	3	0	4	0	0	0	0	0	8	2
Fomesafen	280	8	2	8	2	0	0	0	0	13	0
Fomesafen	350	9	3	8	6	0	0	0	0	16	2
Fomesafen	420	8	3	12	7	0	0	0	0	32	5
Fomesafen	490	9	0	16	10	0	0	0	0	25	4
Fomesafen	560	11	2	21	15	0	0	0	0	37	9
Fomesafen	840	15	2	24	16	0	0	0	0	45	10
Fluometuron	1120	4	2	2	0	0	0	0	0	2	12
Pyrithiobac	60	13	4	6	3	0	0	0	0	8	12
LSD (0.05)		4	ns	7	5	ns	ns	ns	ns	2	9

[z] Early season injury recorded 14 to 28 d after emergence.

[y] Mid-season injury recorded 44 to 75 d after emergence.

In North Carolina and Virginia, early season cotton injury by fomesafen was expressed as foliar necrosis. Cotton typically emerges 5 to 7 d after planting, and rainfall during this period in North Carolina and Virginia totaled 4.3 and 2.9 cm, respectively (Table 2). North Carolina and Virginia were the only locations receiving rainfall during cotton emergence. Price et al. (2004) documented peanut (*Arachis hypogaea* L.) injury by flumioxazin, a herbicide with characteristics and mode of action similar to fomesafen, when irrigation was applied at emergence. Foliar necrosis from fomesafen applied PRE can occur when rainfall is received as cotton is emerging through fomesafen-treated soil. Based on evidence from Price et al. (2004) a significant rainfall event as cotton is emerging likely allows fomesafen to be absorbed by the cotton shoot tissue as the seedling is emerging. At a recommended use rate of 280 g ha^{-1}, early season cotton necrosis was 8 and 13% in North Carolina and Virginia, respectively (Table 3). Greater than 15% necrosis was noted in North Carolina at rates of 490 g ha^{-1} or higher and in Virginia at rates of 420 g ha^{-1} or higher. By mid-season, cotton necrosis was 2% or less at a recommended use rate of 280 g ha^{-1}, with injury being equal to or less than that with fluometuron or pyrithiobac (Table 3). In Virginia, plant stands and heights in the non-treated control were similar to those in systems receiving herbicide treatments (Tables 4 and 5). However in North Carolina, plant stands were reduced 23% to 28% by fomesafen at 420 g ha^{-1} or higher and with pyrithiobac when compared to the non-treated control. Plant heights were also reduced 11 to 20% by fomesafen when applied at 490 g ha^{-1} or higher. Injury from fomesafen was similar to observations of Kleifeld et al. (1988) where injury was apparent when rain fell just after cotton emergence.

Cotton fruit number and fruit position. Plant mapping conducted in Tennessee and South Carolina revealed that no herbicide treatment impacted the number of main-stem nodes, number of effective sympodia, node of the first effective sympodium, sympodial boll retention, or total boll production (data not shown).

Table 4. Cotton stands with fomesafen applied PRE.[z]

Herbicides	Application rate (g ha^{-1})	Stand (plants 9.1 m^{-1} of row)				
		Georgia	North Carolina	South Carolina	Tennessee	Virginia
Untreated	--	85	64	96	97	67
Fomesafen	140	90	65	92	95	61
Fomesafen	280	95	56	90	92	70
Fomesafen	350	98	57	89	96	61
Fomesafen	420	100	49	88	94	70
Fomesafen	490	87	48	90	89	68
Fomesafen	560	91	46	94	92	58
Fomesafen	840	86	49	96	94	58
Fluometuron	1120	87	59	92	95	69
Pyrithiobac	60	91	52	91	96	69
LSD (0.05)		ns	10	ns	ns	11

[z] Plant stand counts recorded 21 to 35 d after emergence.

Table 5. Cotton height with fomesafen applied PRE.[z]

Herbicides	Application rate (g ha^{-1})	Height (cm)				
		Georgia	North Carolina	South Carolina	Tennessee	Virginia
Untreated	--	6.3	11.0	11.3	20.1	40.0
Fomesafen	140	6.0	11.5	11.0	20.2	44.6
Fomesafen	280	5.8	10.9	11.3	19.7	43.4
Fomesafen	350	5.3	10.3	11.8	19.1	32.3
Fomesafen	420	5.8	10.5	11.0	20.2	36.4
Fomesafen	490	5.0	9.8	10.3	19.3	37.5
Fomesafen	560	4.5	9.7	10.3	18.5	36.9
Fomesafen	840	4.8	8.8	10.8	19.2	35.1
Fluometuron	1120	6.3	11.0	11.0	19.8	32.0
Pyrithiobac	60	4.8	10.3	11.5	17.9	33.4
LSD (0.05)		1.4	0.9	ns	1.3	ns

[z] Plant height recorded 21 to 60 d after emergence.

Cotton yield and fiber quality. Cotton lint yields were similar for all herbicide treatments and were not different from the non-treated control at the Georgia, South Carolina, Tennessee, and Virginia locations (Table 6). These results are similar to previous research where no yield differences were detected with fomesafen applied PRE to cotton (Baumann et al., 1998; Stephenson et al., 2004). Regression analysis of all yield data indicate nearly no correlation between fomesafern rate and cotton yield (r2 = 0.03) (Figure 1). In North Carolina, where fomesafen at 560 and 840 g ha^{-1} caused 21 and 24% visible necrosis early season and 15 to 16% necrosis during mid-season (Table 3) and reduced plant stands and plant heights (Tables 4 and 5), cotton yield was also reduced 23 to 25% (Table 6). Cotton yield was not affected by fomesafen at registered rates of 280 to 420 g ha^{-1}. Herbicides had no effect on fiber length, fiber strength, fiber length uniformity, or micronaire in North Carolina and South Carolina, the two locations where these data were recorded (data not shown).

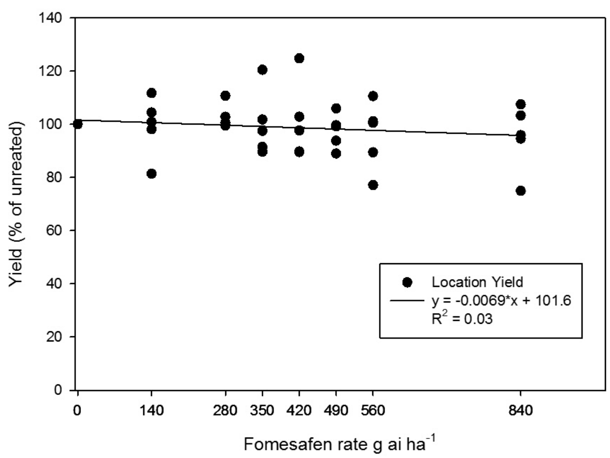

Figure 1. Regression analysis of cotton yield response to fomesafen.

Table 6. Cotton yield following PRE application of fomesafen.

Herbicides	Application rate (g ha^{-1})	Lint yield (kg ha^{-1}) Georgia	North Carolina	South Carolina	Tennessee	Virginia
Untreated	--	1720	1170	1180	1350	1740
Fomesafen	140	1790	1180	1190	1260	1420
Fomesafen	280	1770	1180	1200	1540	1560
Fomesafen	350	1750	1070	1280	1310	1570
Fomesafen	420	1690	1050	1330	1400	1640
Fomesafen	490	1720	1040	1060	1460	1670
Fomesafen	560	1740	900	1070	1540	1560
Fomesafen	840	1640	880	1140	1410	1670
Fluometuron	1120	1700	1130	1100	1500	1700
Pyrithiobac	60	1580	1140	1030	1340	1700
LSD (0.05)		ns	140	ns	ns	ns

Our research documents that the impact of fomesafen on cotton emergence is directly related to rainfall that occurs from planting through cotton emergence. Heavy rain that occurs prior to cotton emergence can cause cotton stunting while rainfall that occurs during cotton emergence can cause significant cotton necrosis and possibly stand loss. Results from this research indicate that fomesafen can be safely applied PRE to cotton at labeled rates without sacrificing yield as long as plant stand reductions do not occur. Plant stand reductions with this experiment only occurred at 1 of 5 locations and only when rates 1.75 times greater than the normally recommended use rate of 280 g ha^{-1} were applied. Although cotton injury from fomesafen may occur across the southeastern U.S. cotton belt, the potential for significant injury is far less than the value of fomesafen in managing GR Palmer amaranth (Culpepper and Steckel, 2010; Kichler et al., 2010; Marshall, 2009; Whitaker, 2009).

LITERATURE CITED

Anonymous. 2011. Reflex herbicide label. Syngenta Crop Protection, Inc., Greensboro, NC [Online]. Available at http://www.cdms.net/LDat/ld6BJ013.pdf (verified 21 Nov. 2011).

Askew, S.D., W.A. Bailey, G.H. Scott, and J.W. Wilcut. 2002. Economic assessment of weed management for transgenic and non-transgenic cotton in tilled and no-tilled systems. Weed Sci. 50:512-520.

Baumann, P.A., J.W. Keeling, G.D. Morgan, and J.W. Smith. 1998. Evaluation of fomesafen for weed control in Texas cotton. p. 43-44. *In* Proc. South. Weed Sci. Soc., Birmingham, AL. 26-28 Jan. 1998. South. Weed. Sci. Soc., Champaign, IL.

Branson, J.W., K.L. Smith, and J.L. Barrentine. 2005. Comparison of trifloxysulfuron and pyrithiobac in glyphosate-resistant and bromoxynil-resistant cotton. Weed Technol. 19:404-410.

Brewer, C.E., and L.R. Oliver. 2009. Confirmation and resistance mechanisms in glyphosate-resistant common ragweed (*Ambrosia artemisiifolia*) in Arkansas. Weed Sci. 57:567-573.

Corbett, J.L., S.D. Askew, W.E. Thomas, and J.W. Wilcut. 2004. Weed efficacy evaluationsfor bromoxynil, glufosinate, glyphosate, pyrithiobac, and sulfosate. Weed Technol. 18:443-453.

Culpepper, A.S., T.L. Grey, W.K. Vencill, J.M. Kichler, T.M. Webster, S.M. Brown, A.C. York, J.W. Davis, and W.W. Hanna. 2006. Glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*) confirmed in Georgia. Weed Sci. 54:620-626.

Culpepper, A.S., and L. Steckel. 2010. Value of Transgenic Crops – Weed Management. p 6. *In* Proc. Beltwide Cotton Conf., New Orleans, LA. 4-7 Jan. 2010. Natl. Cotton Counc. Am., Memphis, TN.

Culpepper, A S. and A.C. York. 1998. Weed management in glyphosate-tolerant cotton. J. of Cotton Sci. 2:174-185.

Frans, R., R. Talbert, D. Marx, and H. Crowley. 1986. Experimental design and techniques for measuring and analyzing plant responses to weed control practices. p. 29-46. *In* N.D. Camper (ed.) Research Methods in Weed Science. 3rd ed. South. Weed Sci. Soc., Champaign, IL.

Gardner, A.P., A.C. York, D L. Jordan, and D.W. Monks. 2006. Management of annual grasses and *Amaranthus* spp. in glufosinate-resistant cotton. J. Cotton Sci. 10:328-338.

Heap, I. 2011. The International Survey of Resistant Weeds [Online]. Available at http://www.weedscience.org. (verified 9 Jan. 2012).

Kichler, J.M., A.S. Culpepper, and J.E. Chafin. 2010. Glyphosate-resistant Palmer amaranth and cotton response to residual at-plant herbicides applied on the soil surface or preplant incorporated. p. 1654. *In* Proc. Beltwide Cotton Conf., New Orleans, LA. 4-7 Jan. 2010. Natl. Cotton Counc. Am., Memphis, TN.

Kichler, J.M., A.S. Culpepper, A.C. York, A.W. MacRae, and J. Whitaker. 2008. Managing glyphosate-resistant Palmer amaranth with residual herbicides. p. 1691-1692. *In* Proc. Beltwide Cotton Conf., Nashville, TN. 8-11 Jan. 2008. Natl. Cotton Counc. Am., Memphis, TN.

Kichler, J.M., A S. Culpepper, A.C. York, and L.M. Sosnoskie. 2009. Managing glyphosate-resistant Palmer amaranth in conservation tillage. p. 1344-1345. *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 5-8 Jan. 2009. Natl. Cotton Counc. Am., Memphis, TN.

Kleifeld, Y., T. Blumenfield, G. Herzlinger, S. Graph, H. BuxBaum, and A. Bargutti. 1988. The use of fomesafen for pre-emergence weed control in cotton. Phytoparasitica 16:133-144.

MacRae, A.W., A.S. Culpepper, T.M. Webster, L.M. Sosnoskie, and J.M. Kichler. 2008. Glyphosate-resistant Palmer amaranth competition with Roundup Ready cotton. p. 1696. *In* Proc. Beltwide Cotton Conf., Nashville, TN. 8-11 Jan. 2008. Natl. Cotton Counc. Am., Memphis, TN.

Main, C.L., T.C. Mueller, R.M. Hayes, and J.B. Wilkerson. 2004. Response of selected horseweed (*Conyza canadensis* (L.) Cronq.) populations to glyphosate. J. Agric. Food Chem. 52:879-883.

Marshall, M.W. 2009. Herbicide program alternatives for glyphosate-resistant Palmer amaranth (A*maranthus palmeri* S. Wats.) control in cotton. p. 1331. *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 5-8 Jan. 2009. Natl. Cotton Counc. Am., Memphis, TN.

Mills, M S., and N.D. Simmons. 1998. Assessing the ground-water contamination potential of agricultural chemicals: a flexible approach to mobility and degradation studies. Pestic. Sci. 54:418-434.

Nandula, V.K., D.H. Poston, T.W. Eubank, C.H. Koger, and K.N. Reddy. 2007. Differential response to glyphosate in Italian ryegrass (*Lolium multiflorum*) populations from Mississippi. Weed Technol. 21:477-482.

Nichols, R.L., J. Bond, A.S. Culpepper, D. Dodds, V. Nandula, C.L. Main, M.W. Marshall, T. C. Mueller, J.K. Norsworthy, A. Price, M. Patterson, R.C. Scott, K.L. Smith, L.E. Steckel, D. Stephenson, D. Wright, and A.C. York. 2009. Glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*) spreads in the southern United States [Online]. Resistant Pest Management Newsletter 18:8-10. Available at http://whalonlab.msu.edu/Newsletter/pdf/18_2.pdf (verified 21 Mar. 2010).

Northsworthy, J.K., R. Jha, L.E. Steckel, and R.C. Scott. 2010. Confirmation and control of glyphosate-resistant giant ragweed (*Ambrosia trifida*) in Tennessee. Weed Technol. 24:64-70.

Price, A.J., J.W. Wilcut, and J.R. Cranmer. 2004. Physiological behavior of root-absorbed flumioxazin in peanut, ivyleaf morningglory (*Ipomoea hederacea*), and sicklepod (*Senna obtusifolia*). Weed Sci. 52:718-724.

Reiling, K.R., F.W. Simmions, D.E. Reichers, and L.E. Steckel. 2006. Application timing and soil pH effects on sulfentrazone phytotoxicity to two soybean (*Glycine max* (L) Merr.) cultivars. J. Crop Prot. 25:230-234.

Sasser, P.E. 1981. The basics of high volume instruments for fiber testing. p. 191-193. *In* Proc. Beltwide Cotton Conf., New Orleans, LA. 4-8 Jan. 1981. Natl. Cotton Counc. Am., Memphis, TN.

Sosnoskie, L.M., J.M. Kichler, R. Wallace, and A.S. Culpepper. 2009. Multiple resistance to glyphosate and ALS-inhibitors in Palmer amaranth in cotton. p. 1351-1352. *In* Proc Beltwide Cotton Conf., San Antonio, TX. 5-8 Jan. 2009. Natl. Cotton Counc. Am., Memphis, TN.

Spadotto, C.A. 2002. Screening method for assessing pesticide leaching potential. Pesticidas: R. Ecotoxicol. E Meio Ambiente, Curitiba 12:69-78.

Stephenson , D.O., M.G. Patterson, W.H. Faircloth, and J.N. Lunsford. 2004. Weed management with fomesafen preemergence in glyphosate resistant cotton. Weed Technol. 18:680-686.

Taylor-Lovell, S., L.M. Wax, and R. Nelson. 2001. Phytotoxic response and yield of soybean (*Glycine max*) varieties treated with sulfentrazone or flumioxazin. Weed Technol. 15:95-102.

Troxler, S.C., S.D. Askew, J.W. Wilcut, W.D. Smith, and M.D. Paulsgrove. 2002. Clomazone, fomesafen, and bromoxnil systems for bromoxynil resistant cotton (*Gossypium hirsutum*). Weed Technol. 16:838-844.
VanGessel, M.J. 2001. Glyphosate-resistant horseweed in Delaware. Weed Sci. 49:703-705.

Weber, J.B., H.J. Strek, and J.L. Sartor. 1993. Mobility of fomesafen and atrazine in soil columns under saturated- and unsaturated-flow conditions. Pestic. Sci. 39:39-46.

Whitaker, J.R. 2009. Distribution, biology and management of glyphosate-resistant Palmer amaranth in North Carolina [Online]. Ph.D. diss. North Carolina State Univ., Raleigh, NC. Available at http://www.lib.ncsu.edu/theses/available/etd-03272009-143230 (verified 9 Jan. 2012).

Wilcut, J.W., A.C. York, and D.L. Jordan. 1995. Weed management programs for oil seed crops. p. 343-400. *In* A.E. Smith (ed.). Handbook of Weed Management Systems. Marcel Dekker, New York, NY.

Wise, A.M., T.L. Grey, E.P. Prostko, W.K. Vencill, and T.M. Webster. 2009. Establishing the geographic distribution level of acetolactate synthase resistance of Palmer amaranth (*Amaranthus palmeri*) accessions in Georgia. Weed Technol. 23:214-220.

Young, B.G. 2006. Changes in herbicide use patterns and production practices resulting from glyphosate-resistant crops. Weed Technol. 20:301-307.