Weed Technology

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Residual weed control in cotton utilizing herbicide-coated fertilizer

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Research Article

Cite this article: Dean BA, Cahoon CW, Collins GD, Jordan DL, Taylor ZR, Forehand JC, de Sanctis JS, Lee JH (2025) Residual weed control in cotton utilizing herbicide-coated fertilizer. Weed Technol. **39**(e15), 1–7. doi: 10.1017/wet.2024.94

Received: 9 August 2024
Revised: 15 October 2024
Accepted: 12 November 2024

Associate Editor:
Lawrence E. Steckel, University of Tennessee

Nomenclature:
Acetochlor; atrazine; dimethenamid-*P*; diuron; flumioxazin; fluometuron; fluridone; fomesafen; glufosinate; glyphosate; linuron; metribuzin; pendimethalin; pyroxasulfone; pyroxasulfone + carfentrazone; *S*-metolachlor; sulfentrazone; Palmer amaranth, *Amaranthus palmeri* S. Watson. AMAPA; cotton, *Gossypium hirsutum* L.

Keywords:
Cotton tolerance; impregnated fertilizer

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Abstract

An experiment was conducted in 2022 and 2023 near Rocky Mount and Clayton, NC, to evaluate residual herbicide-coated fertilizer for cotton tolerance and Palmer amaranth control. Treatments included acetochlor, atrazine, dimethenamid-*P*, diuron, flumioxazin, fluometuron, fluridone, fomesafen, linuron, metribuzin, pendimethalin, pyroxasulfone, pyroxasulfone + carfentrazone, *S*-metolachlor, and sulfentrazone. Each herbicide was individually coated on granular ammonium sulfate (AMS) and top-dressed at 321 kg ha^{-1} (67 kg N ha^{-1}) onto 5- to 7-leaf cotton. The check plots received the equivalent rate of nonherbicide-treated AMS. Before top-dress, all plots (including the check) were treated with glyphosate and glufosinate to control previously emerged weeds. All herbicides except metribuzin resulted in transient cotton injury. Cotton response to metribuzin varied by year and location. In 2022, metribuzin caused 11% to 39% and 8% to 17% injury at the Clayton and Rocky Mount locations, respectively. In 2023, metribuzin caused 13% to 32% injury at Clayton and 73% to 84% injury at Rocky Mount. Pyroxasulfone (91%), pyroxasulfone + carfentrazone (89%), fomesafen (87%), fluridone (86%), flumioxazin (86%), and atrazine (85%) controlled Palmer amaranth ≥85%. Pendimethalin and fluometuron were the least effective treatments, resulting in 58% and 62% control, respectively. As anticipated, early season metribuzin injury translated into yield loss; plots treated with metribuzin yielded 640 kg ha^{-1} and were comparable to yields after linuron (790 kg ha^{-1}) was used. These findings suggest that with the exception of metribuzin, residual herbicides coated onto AMS may be suitable and effective in cotton production, providing growers with additional modes of action for late-season control of multiple herbicide–resistant Palmer amaranth.

Introduction

In recent years, cotton producers have had to navigate high production costs, which increased by an estimated US $459 ha^{-1} between 2018 and 2022 (USDA-ERS 2023a). This rise in expense is partly due to the prevalence of multiple herbicide–resistant (HR) weed species such as Palmer amaranth. The need for expensive herbicide programs and advanced application technology, coupled with the continued rise in herbicide-tolerant cottonseed costs, has further highlighted the financial challenges of managing multiple-HR weed biotypes (Korres et al. 2019; Ofosu et al. 2023; USDA-ERS 2023b). Historically, growers could simply and cost-effectively manage Palmer amaranth by concurrently using postemergence herbicides and herbicide-tolerant cultivars (Duke and Powles 2008). However, Palmer amaranth biotypes have evolved resistance to many of the postemergence herbicides available for use in cotton (Foster and Steckel 2022; Heap 2024; Jones 2022), thus necessitating more focus on alternative weed control strategies.

Before herbicide-resistant cotton cultivars appeared on the market, it was commonplace to layer residual herbicides with multiple effective modes of actions (MOAs) (Culpepper et al. 2010; Prostko et al. 2001). A standard recommendation of the time would have included pendimethalin or trifluralin applied preplant-incorporated (PPI), followed by a photosystem II (PS II) inhibitor such as diuron or fluometuron, applied preemergence. If warranted, a postemergence-directed application that included cyanazine, diuron, fluometuron, or prometryn + MSMA or DSMA, would follow to ensure adequate late-season weed control (Wilcut et al. 1995). Like the aforementioned strategy, extension weed specialists currently advise similar programs to effectively manage multiple-HR Palmer amaranth and to further delay the evolution of herbicide resistance (Busi et al. 2020; Cahoon and York 2024; Neve et al. 2011). Soil-residual herbicides routinely applied preemergence to control Palmer amaranth in cotton include the protoporphyrinogen oxidase (PPO) inhibitor fomesafen, the very-long-chain-fatty-acid (VLCFA) inhibitor acetochlor, and the photosystem II (PS II) inhibitors diuron and fluometuron (Whitaker et al. 2011). However, diuron, which has been determined to be a carcinogen and fluometuron, which may leach into groundwater, are under review by the U.S. Environmental Protection Agency, bringing into question the longevity of these herbicides for managing Palmer amaranth (USEPA 2022). In the potential absence of diuron and fluometuron, alternative options remain available to combat weeds in cotton, including the phytoene desaturase inhibitor fluridone and the microtubule inhibitor pendimethalin.

Residual herbicides registered for postemergence over-the-top (OTT) use on cotton are relatively limited; the VLCFA inhibitors, including acetochlor, dimethenamid-*P*, and *S*-metolachlor, are the predominate options. These herbicides provide effective residual control of Palmer amaranth but do not control emerged weeds (Hay 2017; Riar et al. 2012). In 2024, transgenic cotton cultivars that are tolerant to the herbicide isoxaflutole were commercially launched. Isoxaflutole, an herbicide that inhibits 4-hydroxyphenylpyruvate dioxygenase (HPPD), will offer growers an additional tool for managing Palmer amaranth preemergence and/or early postemergence, following the official release of the cotton formulation (Farr et al. 2022; Joyner et al. 2022). Like the VLCFA inhibitors, isoxaflutole does not effectively control emerged Palmer amaranth (Joyner 2021). The ALS-inhibiting herbicides, including trifloxysulfuron and pyrithiobac, provide additional postemergence residual options for weed control in cotton. However, Palmer amaranth biotypes that are resistant to ALS-inhibiting herbicides are widespread, ultimately hindering their use (Nakka et al. 2017; Norsworthy et al. 2008). Beyond the aforementioned herbicides, no other postemergence-OTT residual herbicides are available for use in cotton production.

Despite limited postemergence-OTT residual herbicides, additional options exist for controlling Palmer amaranth using postemergence-directed lay-by and hooded sprayer applications. These applications direct and/or shield the spray beneath the cotton foliage to avoid the risk of plant injury. In cotton, the available herbicide options include the PS II inhibitors diuron, fluometuron, and prometryn; the VLCFA inhibitors acetochlor, *S*-metolachlor, and pyroxasulfone; and the PPO inhibitors fomesafen and flumioxazin (Cahoon and York 2024, Wilcut et al. 1995). Although many residual herbicides are registered for postemergence-directed use in cotton, these products are seldom used in this capacity. This is partly because applying herbicides postemergence-directed is time- and labor-intensive, and following the commercialization of glyphosate-tolerant cotton, many growers replaced such methods of weed control for simple and cost-effective postemergence-only programs (Webster and Sosonskie 2010). Additionally, postemergence-directed applications require a height difference between the cotton and targeted weeds to prevent cotton injury, which is difficult to obtain due to the robust growth of Palmer amaranth (Askew et al. 2002).

Due to the infrequent use of postemergence-directed herbicides, greater dependence on, and consequently, greater selection pressure for resistance have been imposed on the few remaining postemergence-OTT residual options. Currently, Palmer amaranth biotypes that are resistant to HPPD and VLCFA inhibitors have been discovered, bringing to question the longevity of these important MOAs (Brabham et al. 2019; Mahoney et al. 2020). With weed control costs continuing to rise and the rate of herbicide discovery at a near standstill (Beckie and Harker 2017; Washburn 2023), there is a pressing need for alternative weed control strategies that have the potential to integrate additional herbicide MOAs into cotton weed management.

Given that growers frequently apply fertilizer within a growing season (Edmisten and Collins 2023), especially on the sandy soils of the southern U.S. cotton production region (Gatiboni and Hardy 2023), one potential weed management strategy is residual herbicide-coated fertilizer. Buhler (1987) reported that herbicide-coated fertilizer could reduce time, labor costs, and soil compaction. In turfgrass and container nurseries, herbicide-coated fertilizer is commonly used to prevent herbicide volatility and to reduce the risk of injury (Derr 1994; Yelverton 1998). Since herbicide-coated granules are more likely to fall to the ground than adhere to crop foliage, less crop injury could be expected compared to spray applications. As a result, herbicide-coated fertilizer may have the potential to integrate additional herbicide MOAs into cotton with minimal risk of injury. Additionally, herbicide-coated fertilizer could provide cotton growers with an alternative to applying postemergence-directed herbicides (Steckel 2021).

Currently, pendimethalin and pyroxasulfone are the only herbicides registered to be applied coated onto granular fertilizer in cotton (Anonymous 2024a, 2024c). Pendimethalin-coated fertilizer has been shown to control Texas millet (*Urochloa texana* R. Webster) similarly to pendimethalin sprayed at planting (Grey et al. 2008). Research in North Carolina found that pyroxasulfone-coated granular ammonium sulfate (AMS) controlled Palmer amaranth to an extent that was comparable to pyroxasulfone applied postemergence and postemergence-directed (Dean et al. 2023). Although some studies have evaluated the use of herbicide-coated fertilizer in cotton, further studies are needed to investigate the efficacy and utility of additional herbicide MOAs coated onto AMS fertilizer in cotton. Thus, the objectives of this research were to evaluate cotton tolerance to top-dress applications of various herbicides coated onto granular AMS fertilizer and to evaluate their efficacy in controlling Palmer amaranth.

Materials and Methods

An experiment was conducted in 2022 and 2023 at the Upper Coastal Plains Research Station near Rocky Mount, NC (35.89°N, 77.68°W), and the Central Crops Research Station near Clayton, NC (35.67°N, 78.51°W). The soil at the Rocky Mount location consisted of an Aycock very fine sandy loam (Fine-silty, siliceous, subactive, thermic Typic Paleudults) with 0.3% to 0.4% humic matter and pH of 6.0 to 6.1. The soil at the Clayton location consisted of a Dothan loamy sand (Loamy, kaolinitic, thermic Arenic Kandiudults) with 0.3% to 0.4% humic matter and pH of 5.5 to 6.0 (Mehlich 1984).

Fields at both locations were prepared using conventional tillage and then bedded into 91-cm rows at Rocky Mount and 97-cm rows at Clayton. Plots were four rows wide by 9.1-m long. Deltapine® cotton cultivar 'DP 2115 B3XF' (Bayer CropScience, Research Triangle Park, NC) was planted on May 11, 2022, at Rocky Mount and May 12, 2022, at Clayton. In 2023, 'DP 2115 B3XF' cotton cultivar was planted at Rocky Mount on May 9, whereas Deltapine ThryvOn™ cotton cultivar 'DP 2211 B3TXF' was planted at Clayton on May 11. Cotton was seeded at approximately 107,637 seeds ha^{-1} to a 2- to 2.5-cm depth. All pesticides and fertilizers required for crop maintenance were applied following recommendations from North Carolina Cooperative Extension (Edmisten et al. 2024).

Treatments included 15 residual herbicides plus a check. Herbicides and application rates are reported in Table 1. Treatments were arranged in a randomized complete block design with four replications. Each herbicide was coated onto granular

https://doi.org/10.1017/wet.2024.94

Table 1. Residual herbicide treatments applied top-dress, coated on granular ammonium sulfate fertilizer[a].

Herbicide	Trade name	Formulation concentration	Application rate	Manufacturer
		g ai L^{-1}	g ai ha^{-1}	
acetochlor	Warrant®	360	1,260	Bayer CropScience
Atrazine	Atrazine® 4L	480	1,120	Adama US
Dimethenamid-*P*	Outlook®	719	630	BASF Corporation
Diuron	Direx®	480	840	Makhteshim Agan of North America
Flumioxazin	Valor® EZ	480	52	Valent U.S.A
Fluometuron	Cotoran® 4L	480	1,120	Adama US
Fluridone	Brake®	144	221	SePRO Corporation
Fomesafen sodium salt	Reflex®	240	280	Syngenta Crop Protection
Linuron	Linex® 4L	480	840	NovaSource, Inc
Metribuzin	TriCor®	75%	420	UPL NA, Inc
Pendimethalin	Prowl® H20	455	1,064	BASF Corporation
Pyroxasulfone	Zidua® SC	500	118	BASF Corporation
Pyroxasulfone + carfentrazone-ethyl	Anthem® Flex	447 + 32	118 + 9	FMC Corporation
S-metolachlor	Dual Magnum®	913	1,067	Syngenta Crop Protection
Sulfentrazone	Spartan®	480	210	FMC Corporation

[a]Specimen labels for each product and mailing addresses and website of each manufacturer can be found at www.cdms.net.

Table 2. Top-dress application dates and accumulated rainfall after applications at both experimental locations.

Location	Year	Application date	Days following application					
			0–8	9–16	17–24	25–32	33–40	40–48
			cm					
Rocky Mount	2022	June 16	2.44	0.02	6.1	0.46	0.08	6.55
	2023	June 21	4.52	1.48	8.03	0.23	0.97	0.36
Clayton	2022	June 17	0.66	0.58	7.54	0.97	0.08	3.3
	2023	June 21	3.21	5.29	5.96	0.08	0.06	1.84

AMS (21-0-0-24; FCI Agri Service Company, Raeford, NC) and applied at 321 kg ha^{-1} (67 kg N ha^{-1}) onto 5- to 7-leaf cotton. This timing matches when a typical fertilizer application would be made to fulfill peak fertility demand during cotton squaring. The check received the equivalent rate of nonherbicide-treated AMS for comparison. Herbicide-coated AMS was prepared by mixing the desired rate of herbicide, water, and 1 mL of blue dye (45 mL of the total solution) in an electric-powered concrete mixer (Sears, Hoffman Estates, IL) that contained the appropriate rate of granular AMS. The blue dye (1 mL) was included in the mixture to provide a means for visually estimating coverage throughout the mixing process. All treatments were evenly top-dressed within three cotton row middles using 1.89-L plastic containers (ULINE, Pleasant Prairie, WI) with lids that had equally spaced and sized (approximately 4 mm) holes. Prior to applications, all plots (including the check) were treated with glyphosate (Roundup PowerMAX® 3 Herbicide; Bayer CropScience) at 1,345 g ae ha^{-1} and glufosinate (Liberty® 280 SL Herbicide; BASF Corporation, Research Triangle Park, NC) at 656 g ai ha^{-1} to control previously emerged weeds. No residual herbicides were used prior to treatment applications. Herbicides were applied using a CO_2-pressurized backpack sprayer calibrated to deliver 140 L ha^{-1} at 207 kPa. Backpack sprayers were equipped with TeeJet AIXR 11002 flat-fan nozzles (Spraying Systems Co., Glendale Heights, IL). Application dates and accumulated rainfall at both locations in both years are reported in Table 2.

All locations were naturally infested with Palmer amaranth. Percentage of cotton injury and weed control were estimated visually according to Frans et al. (1986) until 70 d after treatment (DAT). Additionally, late-season Palmer amaranth density was measured before cotton defoliation by randomly placing two 0.25-m^2 quadrats per plot and counting the number of individuals within each quadrat. At the conclusion of the season, the center two rows of each plot were mechanically harvested and weighed to determine cotton lint yield. All data were subject to ANOVA using the GLM procedure with SAS software (v. 9.4; SAS Institute Inc., Cary, NC) ($\alpha = 0.05$) (Saville 2015). Treatment means were separated using Fisher's protected LSD ($P \leq 0.05$) where appropriate. For all analyses, treatment, year, location, and their interactions were considered fixed effects, while replication was considered a random effect.

Results and Discussion

Cotton Response

Main effects of treatment, year, and location were significant for cotton injury. The three-way interaction of the main effects was significant; thus, data for cotton injury are presented by location. Most injury was in the form of cotton necrotic leaf specking and resulted from AMS granules adhering to damp foliage at time of application. However, interveinal and marginal leaf chlorosis was characteristic of the PS II inhibitors, including diuron, fluometuron, linuron, atrazine, and metribuzin. These herbicides are apoplastically translocated (moving upward through the plant from the soil) throughout the plant and can be absorbed through foliage or roots (Ross and Childs 1996). When soil-applied, plant roots can readily absorb these herbicides, causing chlorophyll synthesis inhibition and degradation of cell membranes (Neal et al. 2015).

At 7 DAT in 2022, sulfentrazone was the most injurious at both locations, resulting in 18% and 11% cotton injury at Clayton and

https://doi.org/10.1017/wet.2024.94

Table 3. Cotton injury as affected by residual herbicide-coated granular ammonium sulfate fertilizer, 2022 at both experimental locations[a–e].

	Cotton injury					
	Clayton			Rocky Mount		
Herbicide	7 DAT	28 DAT	42 DAT	7 DAT	28 DAT	42 DAT
	%					
None	4 ef	3 b	0 b	4 d	3 bc	0 b
Acetochlor	7 c	4 b	0 b	2 gh	3 bc	0 b
Atrazine	3 f	3 b	0 b	1 h	3 bc	0 b
Dimethenamid-*P*	5 de	5 b	0 b	3 d-g	3 bc	0 b
Diuron	3 f	3 b	0 b	2 gh	3 bc	0 b
Flumioxazin	6 cd	4 b	0 b	4 de	3 bc	0 b
Fluometuron	3 f	4 b	0 b	1 h	2 c	0 b
Fluridone	4 ef	4 b	0 b	3 d-g	2 c	0 b
Fomesafen	12 b	7 b	0 b	8 b	5 b	0 b
Linuron	6 cd	7 b	0 b	4 d	5 bc	0 b
Metribuzin	11 b	18 a	39 a	8 b	12 a	17 a
Pendimethalin	5 cde	3 b	0 b	2 gh	3 bc	0 b
Pyroxasulfone	4 ef	3 b	0 b	4 d	3 bc	0 b
Pyrox + carfen	7 cd	4 b	0 b	6 c	4 bc	0 b
S-metolachlor	5 cde	4 b	0 b	4 def	2 c	0 b
Sulfentrazone	18 a	7 b	0 b	11 a	5 bc	0 b

[a]Abbreviations: AMS, ammonium sulfate; DAT, days after treatment; pyrox + carfen, pyroxasulfone + carfentrazone.
[b]Data are presented by year and location. Means within a column followed by the same letter are not statistically different according to Fisher's protected LSD ($P \le 0.05$).
[c]Each herbicide was coated on granular AMS and top-dressed at 321 kg ha^{-1} onto 5- to 7-leaf cotton.
[d]The check received nonherbicide-treated granular AMS at 321 kg ha^{-1}.
[e]Prior to top-dress, all plots (including the check) were treated with glyphosate at 1,345 g ae ha^{-1} and glufosinate at 656 g ai ha^{-1}.

Table 4. Cotton injury as affected by residual herbicide-coated granular ammonium sulfate fertilizer, 2023 at both experimental locations[a–e].

	Cotton injury					
	Clayton			Rocky Mount		
Herbicide	7 DAT	28 DAT	42 DAT	7 DAT	28 DAT	42 DAT
	%					
None	0 d	0 b	0 b	0 g	0 b	0 b
Acetochlor	0 d	0 b	0 b	2 efg	0 b	0 b
Atrazine	0 d	0 b	0 b	0 g	0 b	0 b
Dimethenamid-*P*	1 d	0 b	0 b	2 efg	0 b	0 b
Diuron	1 d	0 b	0 b	3 e	0 b	0 b
Flumioxazin	13 b	0 b	0 b	11 bc	0 b	0 b
Fluometuron	0 d	0 b	0 b	1 efg	0 b	0 b
Fluridone	3 cd	0 b	0 b	3 ef	0 b	0 b
Fomesafen	9 bc	0 b	0 b	9 cd	0 b	0 b
Linuron	8 bc	0 b	0 b	9 cd	0 b	0 b
Metribuzin	32 a	15 a	13 a	73 a	84 a	81 a
Pendimethalin	0 d	0 b	0 b	1 efg	0 b	0 b
Pyroxasulfone	0 d	0 b	0 b	0 g	0 b	0 b
Pyrox + carfen	8 bc	0 b	0 b	7 d	0 b	0 b
S-metolachlor	0 d	0 b	0 b	1 efg	0 b	0 b
Sulfentrazone	11 b	0 b	0 b	11 bc	0 b	0 b

[a]Abbreviations: AMS, ammonium sulfate; DAT, days after treatment; pyrox + carfen, pyroxasulfone + carfentrazone.
[b]Data are presented by year and location. Means within a column followed by the same letter are not statistically different according to Fisher's protected LSD ($P \le 0.05$).
[c]Each herbicide was coated on granular AMS and top-dressed at 321 kg ha^{-1} onto 5- to 7-leaf cotton.
[d]The check received nonherbicide-treated granular AMS at 321 kg ha^{-1}.
[e]Prior to top-dress, all plots (including the check) were treated with glyphosate at 1,345 g ae ha^{-1} and glufosinate at 656 g ai ha^{-1}.

Rocky Mount locations, respectively (Table 3). Similar to sulfentrazone, metribuzin and fomesafen had a greater cotton response at Clayton than Rocky Mount. At Clayton, metribuzin and fomesafen resulted in 11% and 12% cotton injury, respectively. Meanwhile, both caused 8% injury at Rocky Mount (Table 3). In addition to sulfentrazone (18%), fomesafen (12%), and metribuzin (11%), acetochlor (7%), pyroxasulfone + carfentrazone (7%), flumioxazin (6%), and linuron (6%) all caused injury that was statistically greater than nonherbicide-treated AMS at Clayton 7 DAT (Table 3). Except for sulfentrazone (11%), metribuzin (8%), and fomesafen (8%), pyroxasulfone + carfentrazone (6%) was the only other treatment that caused injury greater than the nonherbicide-treated AMS (4%) at Rocky Mount (Table 3). Notably, atrazine (1%), acetochlor (2%), diuron (2%), fluometuron (1%), and pendimethalin (2%) resulted in statistically less injury than the nonherbicide-treated AMS (4%) at this location (Table 3). Differences in cotton injury between the two locations were likely attributed to rainfall, with Clayton and Rocky Mount accumulating 0.66 and 2.44 cm between 0 and 8 DAT, respectively (Table 2). Due to lower rainfall at Clayton, AMS granules likely remained on cotton foliage for an extended period after top-dress, thus causing slightly greater injury.

By 28 DAT in 2022, all treatments, except metribuzin, resulted in cotton injury that was statistically comparable to the injury observed with nonherbicide-treated AMS (3%) at both locations. Once again, cotton response to metribuzin was greater at Clayton (18%) than Rocky Mount (12%; Table 3). This was further evident 42 DAT, when metribuzin caused 39% and 17% cotton injury at Clayton and Rocky Mount in 2022, respectively (Table 3). Differences between locations were likely due to rainfall and soil texture. Soil texture at Clayton is a loamy sand, while Rocky Mount is a very-fine sandy loam. Between 17 and 40 DAT, Clayton received 1.95-cm more precipitation than Rocky Mount (Table 2). Given the higher sand content at Clayton plus the additional rainfall, metribuzin could have leached into the cotton root zone, thus causing greater root absorption and injury (Kleemann and Gill 2008; Moomaw and Martin, 1978). These findings are further supported by Coble and Schrader (1973), who reported greater soybean (*Glycine max* L. Merr) sensitivity to metribuzin after rainfall was received on coarse-textured soil with low organic matter. In general, these results are expected, because metribuzin cannot be applied to soybeans or many other crops on coarse-textured soil with less than 2% organic matter (Anonymous 2024b). Aside from metribuzin, no other herbicide injured cotton at 42 DAT at either location (Table 3).

Similar to 2022, relatively minor cotton injury was observed at the Rocky Mount and Clayton locations in 2023, except when metribuzin was applied (Table 4). However, cotton tolerance to metribuzin differed in 2023, particularly at the Rocky Mount site. At 7 DAT, metribuzin accounted for 32% and 73% cotton injury at the Clayton and Rocky Mount locations, respectively (Table 4). This response was likely influenced by extensive rainfall that fell in Clayton (2.67 cm) and Rocky Mount (2.74 cm) the first 2 d following top-dress. By 28 and 42 DAT at the Rocky Mount site, metribuzin caused 84% and 81% injury, respectively, whereas at Clayton, 15% and 13% injuries, respectively, were observed (Table 4). Between 9 and 24 DAT, 1.74 cm more rainfall fell at the Clayton location than Rocky Mount (Table 2). Similar to 2022, rainfall likely triggered a cotton response to metribuzin in 2023; however, the heavier rainfall earlier in the season at Clayton, combined with the coarser-textured soil, may have leached metribuzin below the root zone, reducing the amount of herbicide that was bioavailable for root absorption (Shaner 2014). Similar thoughts were reported by VanGessel et al. (2017), suggesting

https://doi.org/10.1017/wet.2024.94

Table 5. Influence of residual herbicide-coated granular ammonium sulfate fertilizer on Palmer amaranth control and density, and cotton lint yield[a–e].

Herbicide	Control 42 DAT	Density[f]	Cotton lint yield
	%	plants m^{-2}	kg ha^{-1}
None	–	9 a	860 ab
Acetochlor	80 b-e	1 e	860 ab
Atrazine	85 a-d	2 de	820 ab
Dimethenamid-*P*	73 e	2 de	910 ab
Diuron	76 de	4 bcd	960 a
Flumioxazin	86 abc	1 e	840 ab
Fluometuron	62 f	6 ab	880 ab
Fluridone	86 abc	4 bcd	830 ab
Fomesafen	87 abc	1 e	950 a
Linuron	77 cde	2 de	790 bc
Metribuzin	78 cde	2 de	640 c
Pendimethalin	58 f	5 bc	850 ab
Pyroxasulfone	91 a	1 e	850 ab
Pyrox + carfen	89 ab	1 e	930 ab
S-metolachlor	73 e	3 b-e	800 b
Sulfentrazone	74 e	3 b-e	820 ab

[a]Abbreviations: AMS, ammonium sulfate; DAT, days after treatment; pyrox + carfen, pyroxasulfone + carfentrazone.
[b]Data are averaged over years and locations. Means within a column followed by the same letter are not statistically different according to Fisher's protected LSD ($P \leq 0.05$).
[c]Each herbicide was coated on granular AMS and top-dressed at 321 kg ha^{-1} onto 5- to 7-leaf cotton.
[d]The check received nonherbicide-treated granular AMS at 321 kg ha^{-1}.
[e]Prior to top-dress, all plots (including the check) were treated with glyphosate at 1,345 g ae ha^{-1} and glufosinate at 656 g ai ha^{-1}.
[f]Density was measured approximately 70 DAT.

substantial rainfall on coarse-textured soil may have increased wheat (*Triticum aestivum* L.) tolerance to metribuzin.

Aside from metribuzin, there was overall less cotton injury in 2023 (Table 4). At the Clayton site, acetochlor, atrazine, dimethenamid-*P*, diuron, fluometuron, pendimethalin, pyroxasulfone, *S*-metolachlor, and the nonherbicide-treated AMS caused no injury 7 DAT (Table 4). This is contrary to results observed in 2022, when those treatments caused 4% to 7% cotton injury at that timing (Table 3). Similar to 2022, pyroxasulfone (0%), *S*-metolachlor (1%), acetochlor (2%), atrazine (0%), fluometuron (1%), pendimethalin (1%), and dimethenamid-*P* (2%) all caused cotton injury that was comparable to that of the nonherbicide-treated AMS at the Rocky Mount site 7 DAT (Table 4).

Over two growing seasons, cotton response to diuron and fluridone was consistent across locations 7 DAT, accounting for 1% to 3% and 3% to 4% cotton injury, respectively (Tables 3 and 4). However, cotton response to flumioxazin varied by year. In 2022, flumioxazin caused 6% and 4% injury at the Clayton and Rocky Mount locations, respectively (Table 3). Meanwhile, in 2023, flumioxazin resulted in 13% injury at Clayton and 11% at Rocky Mount (Table 4). At the Clayton site, sulfentrazone resulted in less injury in 2023 (11%) than in 2022 (18%) (Tables 3 and 4). At the Rocky Mount location, cotton response to sulfentrazone remained consistent, with 11% cotton injury observed in both years. Contrary to 2022, cotton was not injured by any treatment, except metribuzin, 28 DAT in 2023 (Table 4). At both locations, cotton response to metribuzin remained evident 42 DAT (Table 4).

Acetochlor, *S*-metolachlor, and pyroxasulfone applied to cotton postemergence-OTT are reported to cause ≥19% cotton injury (Cahoon et al. 2014; Collie et al. 2014; Eure et al. 2013). However, when coated on granular AMS and applied OTT to 5- to 7-leaf cotton, these herbicides injured cotton by ≤7%. Previous research carried out in Tennessee also reported minimal injury when pyroxasulfone-coated fertilizer was top-dressed in cotton (Steckel 2021). Fluometuron applied postemergence-OTT to cotyledon and 2- to 4-leaf cotton has been reported to cause 40% injury (Kendig et al. 2007). However, when applied on granular AMS, fluometuron accounted for only 1% to 4% injury. Likewise, low doses of flumioxazin applied postemergence-OTT to simulate spray drift has caused 69% to 97% cotton injury (Stephenson et al. 2019). However, flumioxazin-coated AMS caused no greater than 13% cotton injury. Research by Morgan et al. (2011a, 2011b) found that postemergence-directed lay-by applications of diuron, linuron, and fomesafen effectively controlled volunteer cotton. These same herbicides applied coated onto AMS fertilizer in this study resulted in ≤12% cotton injury.

Palmer Amaranth Control

The main effect of treatment was significant for Palmer amaranth control and density; the main effects of year and location were not significant. Furthermore, interactions among main effects were not detected; therefore, Palmer amaranth control and density data were averaged over years and locations (Table 5). Adequate rainfall for herbicide activation fell in both years at both locations (Table 2).

At 42 DAT, all treatments controlled Palmer amaranth by ≥73%, except for pendimethalin and fluometuron, which recorded 58% and 62% control, respectively (Table 5). These results are expected, because pendimethalin and fluometuron have historically provided inconsistent control of Palmer amaranth (Culpepper and York 2000; Grichar 2008). Conversely, pyroxasulfone (91%) was more efficacious than every other treatment, except pyroxasulfone + carfentrazone (89%), fomesafen (87%), fluridone (86%), flumioxazin (86%), and atrazine (85%) (Table 5). Exceptional Palmer amaranth control with pyroxasulfone is unsurprising, given that many studies have also observed >90% control (Cahoon et al. 2015; Janak and Grichar 2016). Apart from fluridone (56%), all the aforementioned herbicides reduced late-season Palmer amaranth density by at least 78% compared with the nonherbicide-treated check (Table 5).

Pyroxasulfone + carfentrazone (89%), fomesafen (87%), fluridone (86%), and flumioxazin (86%) were more efficacious than metribuzin (78%), linuron (77%), diuron (76%), sulfentrazone (74%), *S*-metolachlor (73%), and dimethenamid-*P* (73%) (Table 5). Earlier studies by Whitaker et al. (2011) reported that fomesafen generally provides more effective control of Palmer amaranth than diuron. In general, reductions in Palmer amaranth density followed similar trends as estimates of visual control, with plots treated with diuron containing 56% fewer plants than the nontreated check. In contrast, plots treated with fomesafen had 89% less plants (Table 5). Additionally, atrazine (85%) proved more effective in controlling Palmer amaranth than sulfentrazone (74%), *S*-metolachlor (73%), and dimethenamid-*P* (73%) (Table 5). However, sulfentrazone (74%), *S*-metolachlor (73%), and dimethenamid-*P* (73%) controlled Palmer amaranth to an extent that was comparable to that of acetochlor (80%), metribuzin (78%), linuron (77%), and diuron (76%) (Table 5). Houston et al. (2019) reported similar Palmer amaranth control with *S*-metolachlor, acetochlor, diuron, sulfentrazone, and metribuzin.

Cotton Yield

The main effect of treatment was significant for cotton yield; main effects were not significant for year and location. No significant interactions were detected; therefore, data for cotton yield are

https://doi.org/10.1017/wet.2024.94

presented averaged over years and locations (Table 5). Numerically, cotton treated with diuron (960 kg ha^{-1}) and fomesafen (950 kg ha^{-1}) produced the greatest yield (Table 5). All remaining treatments, except metribuzin, linuron, and *S*-metolachlor, produced similar yields to those of plots treated with diuron or fomesafen. Although plots treated with *S*-metolachlor yielded less than those treated with diuron and fomesafen, the yield was statistically greater than that of metribuzin and comparable to all remaining treatments (Table 5). As expected, due to early season visual injury, cotton treated with metribuzin (640 kg ha^{-1}) yielded the lowest and was only comparable with the yield after linuron (790 kg ha^{-1}) was used (Table 5). Despite yielding similarly to cotton treated with metribuzin, the yield of cotton that had been treated with linuron was comparable to that of all other treatments. It should be noted that the objectives of this research were to evaluate cotton tolerance and weed control with various herbicides applied top-dress, coated on granular AMS fertilizer. Conducting this experiment under weed-free conditions may be more appropriate for evaluating treatment effects on cotton yield. However, yield reductions in response to metribuzin were expected in that significant visual injury was observed earlier in the season.

Practical Implications

Due to the increasing prevalence of multiple-HR Palmer amaranth and the continuous rise in weed control costs, alternative weed management strategies are needed in cotton production. Our results provide evidence that herbicide-coated AMS may allow the integration of additional residual herbicides for late-season weed control in cotton with minimal injury risk. This is important, considering that postemergence residual options for use in cotton production are limited. The integration of additional residual herbicides using this application technique may reduce selection pressure on Group 15 herbicides (as categorized by the Weed Science Society of America), a mode of action on which cotton producers have long depended on. Furthermore, considering that many growers are ill-equipped or hesitant to apply herbicides postemergence-directed, residual herbicide-coated AMS may provide farmers with a more efficient avenue for applying late-season residual herbicides. Simultaneously applying a residual herbicide and fertilizer in a single pass has potential to reduce time, labor, and fuel costs. Although this research proves many herbicides not currently labeled for OTT use in cotton can be safely used when coated on AMS fertilizer, additional research is warranted to further quantify cotton tolerance and potential yield effects under weed-free conditions.

Funding. Funding for this research was provided by the North Carolina Cotton Producers Association through the Cotton Incorporated State Support Program.

Competing Interests. The authors declare they have no competing interests.

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