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Optimizing Pyroxasulfone-Coated Fertilizer in Cotton

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Short title: AI herbicide-resistant weeds

Abstract

Two studies were conducted in 2022 and 2023 near Rocky Mount and Clayton, NC, to determine the optimal granular ammonium sulfate (AMS) rate and application timing for pyroxasulfone-coated AMS. In the rate study, AMS rates included 161, 214, 267, 321, 374, 428, and 481 kg ha^{-1}, equivalent to 34, 45, 56, 67, 79, 90, and 101 kg N ha^{-1}, respectively. All rates were coated with pyroxasulfone at 118 g ai ha^{-1} and top-dressed onto 5- to 7-leaf cotton. In the timing study, pyroxasulfone (118 g ai ha^{-1}) was coated on AMS and top-dressed at 321 kg ha^{-1} (67 kg N ha^{-1}) onto 5- to 7-leaf, 9- to 11-leaf, and first bloom cotton. In both studies, weed control and cotton tolerance to pyroxasulfone-coated AMS was compared to pyroxasulfone applied postemergence (POST) and postemergence-directed (POST-directed). The check in both studies received non-herbicide-treated AMS (321 kg ha^{-1}). Before treatment applications, all plots (including the check) were maintained weed-free with glyphosate and glufosinate. In both studies, pyroxasulfone applied POST was most injurious (8 to 16%), while pyroxasulfone-coated AMS resulted in ≤ 4% injury. Additionally, no differences in cotton lint yield were observed in both studies. With the exception of the lowest rate of AMS (161 kg ha^{-1}; 79%), all AMS rates coated with pyroxasulfone controlled Palmer amaranth ≥ 83%, comparable to pyroxasulfone applied POST (92%) and POST-directed (89%). In the timing study, the application method did not affect Palmer amaranth control; however, applications made at the mid- and late timings outperformed early applications. These results indicate pyroxasulfone-coated AMS can control Palmer amaranth comparable to pyroxasulfone applied POST and POST-directed, with minimal risk of cotton injury. However, the application timing could warrant additional treatment to achieve adequate late-season weed control.

Nomenclature: pyroxasulfone; Palmer amaranth, *Amaranthus palmeri* S. Watson. AMAPA; cotton, *Gossypium hirsutum* L.

Keywords: herbicide-coated fertilizer; impregnated fertilizer

Introduction

Palmer amaranth has become one of the most troublesome weeds across the southern US cotton production region (Van Wychen 2022). If left unmanaged, Palmer amaranth at 3 and 8 plants m^{-1} can reduce cotton yield by as much as 28 and 92%, respectively (MacRae et al. 2013; Morgan et al. 2001; Rowland et al. 1999). In addition to adversely affecting cotton yield, Palmer amaranth densities of 1,300 weeds ha^{-1} can reduce harvest efficiency by as much as 2 hr ha^{-1} (Smith et al. 2000). The ability to control Palmer amaranth has steadily declined due to the rising prevalence of biotypes with resistance to many of the herbicides registered in cotton production (Heap 2024).

In tandem with rising weed management concerns, cotton producers have had to navigate high production costs, which increased by an estimated 31% from 2018 to 2023 (USDA-ERS 2023a). A portion of these expenses are attributed to the input costs of fertilizers, insecticides, and other agrichemicals for early-season cotton development and crop maintenance (Edmisten and Collins 2024). However, the development and spread of multiple herbicide-resistant (HR) weed biotypes, like Palmer amaranth, has rendered weed control one of the more costly components of cotton production (Washburn 2024). 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). Timely pesticide and fertilizer applications are critical for maximizing cotton yield; however, this is often challenging due to the complexities of cotton weed management (Tariq et al. 2020)Given the importance of efficiency and the necessity of effectively managing multiple HR Palmer amaranth, there is a great need to incorporate alternative weed management strategies into cotton production.

In 2020, pyroxasulfone, a very-long-chain-fatty-acid-(VLCFA)-inhibitor (WSSA Group 15), received an amended label allowing it to be coated on granular fertilizer and top-dressed onto cotton (Anonymous 2024). Before the label amendment, pyroxasulfone could only be postemergence-directed (POST-directed) in cotton. This posed challenges, as many growers are ill-equipped or hesitant to apply herbicides POST-directed. Such applications are time- and labor-intensive and require a height difference between the cotton and the targeted weeds, which is often difficult to achieve (Askew et al. 2002; Wilcut et al. 1995)However, pyroxasulfone-coated fertilizer offers growers an alternative to POST-directed applications, with the potential to conserve inputs. Previous research has shown that simultaneously applying herbicide and granular fertilizer can reduce fuel and labor costs and soil compaction (Buhler 1987).

While herbicide-coated fertilizer can improve efficiency, pyroxasulfone has been reported to effectively control Palmer amaranth, with some studies reporting ≥ 90% control 21 DAT (Janak and Grichar 2016; Steele et al. 2005). Aside from Palmer amaranth, pyroxasulfone has also demonstrated activity on troublesome grasses in cotton, including Texas millet [*Urochloa texana* R. Webster.], goosegrass [*Eleusine indica* (L.) Gaertn.], and barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.] (Kharel et al. 2022; Steele et al. 2005; Stephenson et al. 2017; Van Wychen 2022). Although research on pyroxasulfone-coated fertilizer is limited, other studies have demonstrated effective weed control in row crop production systems using herbicide-coated fertilizer (Grey and Webster 2013; Grey et al. 2008; Rabaey and Harvey 1994). One study conducted by Yelverton (1998) reported effective weed control with herbicide-coated fertilizer depended on particle coverage and the timing of application.

Currently, pyroxasulfone is registered to be coated on non-nitrate-based fertilizers and applied at rates ranging from 225 to 785 kg ha^{-1}. Applications can be made on cotton from 5-leaf to the beginning bloom stage (Anonymous 2024). However, recommended fertilizer rates and application timings vary by location, soil texture, and estimated yield potential. On deep, sandy textured soils, typical of the southeastern cotton production region, many growers apply a split or replacement application of nitrogen due to leaching potential (Hons et al. 2004). These applications generally result in small amounts of nitrogen being applied early in the growing season, with the remainder applied at the beginning of boll development (Gatiboni and Hardy 2024). Depending on the timing of application, pyroxasulfone-coated fertilizer may be well-suited for these situations, as it could provide necessary late-season residual following residuals applied at earlier growth stages (Matthew Inman, BASF Corporation, personal communication). However, there are concerns if pyroxasulfone is applied and coated with a low rate of fertilizer, the lack of distribution of the herbicide may jeopardize weed control (Anonymous 2024). Due to frequent applications of low fertilizer rates and variability in application timing, it is imperative to optimize pyroxasulfone-coated fertilizer in cotton production.

The objectives of this research were to determine (1) the optimal granular ammonium sulfate (AMS) rate for applying pyroxasulfone-coated AMS and (2) the optimal application timing for pyroxasulfone-coated AMS to effectively control Palmer amaranth in cotton.

Materials and Methods

Shared Methodology

Two field studies were conducted in 2022 and 2023 at the Upper Coastal Plains Research Station near Rocky Mount, NC (35.89, -77.68), and the Central Crops Research Station near Clayton, NC (35.67, -78.51). The soil at Rocky Mount 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 Clayton 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 and 97-cm rows at Rocky Mount and Clayton, respectively. In both years and at both locations, plots were 4 rows by 9.1-m. 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 depth of 2-2.5 cm. All pesticide and fertilizer applications required for crop maintenance were applied in accordance with recommendations from North Carolina Cooperative Extension (Edmisten et al. 2024).

In both studies, pyroxasulfone (Zidua® SC herbicide, BASF Corp., Research Triangle Park, NC) was applied at 118 g ai ha^{-1} across all treatments. Pyroxasulfone-coated AMS (21-0-0-24; FCI Agri Service Co., Raeford, NC) was prepared by mixing the desired rate of herbicide, water, and 1 ml of blue dye in an electric powered concrete mixer (Sears, Roebuck and Co, USA.) that contained the appropriate rate of granular AMS. The proportion of water-to-AMS was 473 ml water/113 kg AMS, which was suggested as the optimal ratio for preparing pyroxasulfone-coated AMS (Matthew Inman, personal communication, BASF corporation). The blue dye (1 ml) was included in the mixture to provide a means for visually estimating coverage throughout the mixing process. In both studies, the check received 321 kg ha^{-1} of non-herbicide treated AMS as a grower standard for comparison. All fertilizer treatments were evenly top-dressed across the soil surface within three cotton row middles using 1.89 L plastic containers (ULINE Company, U.S.A.) with lids that had equally spaced and sized holes (4 mm). In both years, top-dress applications were made in the morning when dew was present. In addition to a check, both studies included pyroxasulfone applied POST and POST-directed for comparison. Plots treated with pyroxasulfone POST and POST-directed also received 321 kg ha^{-1} of non-herbicide-treated AMS. All spray applications were applied using a CO_2-pressurized backpack sprayer calibrated to deliver 140 L ha^{-1} at 207 kPa. Backpack sprayers were outfitted with AIXR11002 flat-fan nozzles (TeeJet Air Induction XR Flat Spray Tips, TeeJet Technologies, Wheaton, IL) to apply POST applications, and POST-directed applications were applied with a single flood nozzle (TK-VS2 wide angle FloodJet, TeeJet Technologies, Wheaton, IL).

Prior to treatment applications, all plots (including the check) were treated with glyphosate (Roundup PowerMAX® 3 Herbicide, Bayer CropScience, St. Louis, MO) 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. All study locations were naturally infested with Palmer amaranth. Residual Palmer amaranth control was estimated using a scale of 0 to 100, where 0 indicated no control and 100 indicated complete absence of Palmer amaranth (Frans et al. 1986). Cotton injury was similarly evaluated on a scale of 0 to 100, with 0 representing no visible injury and 100 signifying complete plant death (Frans et al. 1986). Visual assessments of cotton injury were a collective measure of plant necrosis, chlorosis, and stunting.

All data were subject to analysis of variance using the GLIMMIX procedure of SAS 9.4 (SAS institute Inc., Cary, NC) ($\alpha = 0.05$). The weedy check was excluded from the statistical analyses for cotton lint yield and weed control in both studies. Treatment means were separated using Tukey's honestly significant difference test ($P \leq 0.05$) where appropriate. In both studies, location, year, replication, and their interactions were considered random effects to allow inferences to be made across broader environmental conditions and locations (Blouin et al. 2011; Moore and Dixon 2015).

Rate Study

Pyroxasulfone (118 g ai ha^{-1}) was coated on granular AMS rates of 161, 214, 267, 321, 374, 428, and 481 kg ha^{-1}, equivalent to 34, 45, 56, 67, 79, 90, and 101 kg N ha^{-1}, respectively. Weed control and cotton tolerance to pyroxasulfone-coated AMS was compared to pyroxasulfone applied POST and POST-directed. All applications were made on 5- to 7-leaf cotton on June 17, 2022, and June 21, 2023. Treatments were arranged in a randomized complete block design (RCBD) with four replications. Weed control and cotton injury were visually estimated bi-weekly until 70 days after treatment (DAT), and late-season Palmer amaranth density was recorded prior to cotton defoliation. At the conclusion of the season, the center two rows of each plot were mechanically harvested and weighed to determine lint yield. For statistical analyses, treatment was considered a fixed effect. Accumulated rainfall received for herbicide activation in both years and at both locations is reported in Table 1.

Timing Study

Treatment structure was a 4 by 3 factorial including 3 application methods plus a check at 3 application timings. Treatments were arranged in a RCBD with four replications. For application methods, pyroxasulfone was applied via coated AMS (321 kg ha^{-1}), POST over-the-top, and POST-directed. Application timings were categorized as Early (5- to 7-leaf), Mid (9- to 11-leaf), and Late (first bloom). For each timing, visual estimates of cotton injury were collected 3 and 7 DAT. At 14 days after late application (DA LA), visual estimates of weed control and cotton injury were collected for each timing and were continued on a bi-weekly schedule until 70 DA LA. In addition to cotton injury and weed control, late season Palmer amaranth density was collected prior to cotton defoliation, and the center two rows of each plot were mechanically harvested and weighed to determine cotton lint yield at the conclusion of the season. For statistical analyses, application method, application timing, and their interaction were considered fixed effects. A significant interaction between application method and timing was observed for cotton response data; therefore, the results are presented accordingly. Application dates and accumulated rainfall in both years and at both locations is reported in Table 2.

Results and Discussion

Rate Study: Palmer amaranth Control

In both years and locations, adequate rainfall was received for herbicide activation (Table 1). No differences in control were observed between pyroxasulfone applied POST (92%) and POST-directed (89%; Table 3). Additionally, every treatment controlled Palmer amaranth comparable to pyroxasulfone applied POST-directed (89%). Despite no differences, it is notable that there was a 10% difference in control between pyroxasulfone applied POST-directed (89%) and coated on 161 kg ha^{-1} of AMS (79%; Table 3). Given the competitive nature of Palmer amaranth and its ability to produce immense amounts of seed (Bensch et al. 2003; Schwartz et al. 2016), this difference may warrant the use of higher rates of pyroxasulfone-coated fertilizer.

With the exception of the lowest rate of AMS (161 kg ha^{-1}), all treatments provided Palmer amaranth control comparable to pyroxasulfone applied POST (Table 3). These results are consistent with earlier research by Skoglund and Gandrud (1984), which demonstrated that herbicide-coated fertilizer can provide weed control equivalent to standard spray applications when applied at appropriate fertilizer rates. Although pyroxasulfone coated on 161 kg ha^{-1} of AMS was less effective than pyroxasulfone applied POST, it performed comparably to all other AMS rates coated with pyroxasulfone (Table 3). No differences in Palmer amaranth density were observed across all treatments, with each treatment reducing plant density by 63 to 88% compared to the non-herbicide treated check (Table 3).

Rate Study: Cotton Response

As anticipated, pyroxasulfone applied POST was the most injurious treatment, resulting in 8 to 12% cotton injury (Table 4). Although these results demonstrate minimal injury with pyroxasulfone applied POST, research on cotton tolerance to pyroxasulfone has widely varied. For instance, Eure et al. (2013) observed significant cotton injury and 19 to 35% yield loss after pyroxasulfone was applied POST, whereas Kroger et al. (2008) observed no yield loss and only 13 to 17% cotton injury when pyroxasulfone was applied to 4-leaf cotton.

For treatments containing AMS, all injury was in the form of cotton necrotic leaf speckling and mostly caused by AMS granules adhering to damp foliage at time of application. Regardless of the AMS rate coated with pyroxasulfone, all injury was ≤ 4% and comparable to injury observed from non-herbicide treated AMS (321 kg ha^{-1}) applied to the check (3%; Table 4). These results are further supported by research from Tennessee, which also reported minimal cotton injury with the use of pyroxasulfone-coated fertilizer in cotton (Steckel 2021). At 3 DAT, pyroxasulfone applied POST-directed (7%) was more injurious than every AMS rate coated with pyroxasulfone (≤ 2%). At 14 DAT, pyroxasulfone POST-directed (5%) remained more injurious than pyroxasulfone coated on 161 to 320 kg ha^{-1} (≤ 3%) of AMS but was comparable to pyroxasulfone coated on 374 to 481 kg ha^{-1} (4%) of AMS (Table 4). These findings suggest that regardless of the AMS rate, pyroxasulfone-coated AMS can likely result in cotton injury that is less than or comparable to pyroxasulfone applied POST-directed. Except for pyroxasulfone applied POST (3%), cotton injury was transient by 28 DAT (data not shown). No differences in cotton lint yield were observed, with yield ranging from 1,040 to 1,210 kg lint ha^{-1} (Table 4).

Timing Study: Palmer amaranth Control

Main effect of application timing was significant for Palmer amaranth control (Table 5). The main effect of application method and the two-way interaction of application timing and application method was not significant (Table 5). However, it is important to understand Palmer amaranth control across application methods. Therefore, data for Palmer amaranth control are presented for application methods averaged over application timings (Table 6), and application timings averaged over application methods (Table 7). Data for Palmer amaranth density are averaged over application timings (Table 6).

Averaged over application timings, there were no differences in visual estimates of Palmer amaranth control across application methods, with each method providing ≥ 90% control 42 DAT (Table 6). Reductions in Palmer amaranth density follow similar trends as visual control estimates, with all treatments resulting in 88% fewer plants compared to the check (Table 6). These findings further suggest that pyroxasulfone-coated AMS (321 kg ha^{-1}, 90%) has potential to control Palmer amaranth similar to pyroxasulfone applied POST (91%) and POST-directed (90%). Excellent control of Palmer amaranth with pyroxasulfone is expected, as many other studies also reported ≥ 90% control (Cahoon et al. 2015; Doherty et al. 2014, Geier et al. 2006).

At 42 DA LA, pyroxasulfone applied at the mid timing (93%) controlled Palmer amaranth similar to pyroxasulfone applied at the late timing (95%; Table 7). However, at the same time, early applications (83%) were less effective than both the mid (93%)- and late (95%)- applications (Table 7). It is important to note that at 42 DA LA, 70 and 56 days had elapsed since the early- and mid-timing applications of pyroxasulfone, respectively. Dissipation studies estimate the residual half-life (DT_{50}) of pyroxasulfone between 8 and 71 days, which may explain reduced control observed by early timing applications compared to later applications (Mueller and Steckel 2011; Mueller 2017; Westra 2012). Following pyroxasulfone applied at the early timing, an additional POST application, including another residual herbicide, would be needed to ensure adequate late-season weed control (Cahoon and York 2024; Culpepper and Vance 2021; Culpepper and Vance 2023). It is important to note that glyphosate and glufosinate were applied POST before treatments at each timing. When considering this, a POST application followed by pyroxasulfone-coated AMS at the mid timing (9- to 11-leaf cotton) could potentially achieve adequate late-season control of Palmer amaranth, especially if used in combination with a strong PRE herbicide program.

Timing Study: Cotton Response

As expected, pyroxasulfone applied POST was the most injurious treatment at each timing. However, pyroxasulfone applied POST at the early (16%) and mid (14%) timings was more injurious than when applied at the late timing (8%; Table 8). Between the early (9%), mid (6%), and late (3%) applications, cotton injury from pyroxasulfone POST-directed followed a consistent trend, with total injury decreasing the later applications were made (Table 8). This is likely attributed to cotton maturity as taller plants generally receive less herbicide contact during POST-directed lay-by applications (Altom et al. 2000; Ferrell et al. 2007). Pyroxasulfone-coated AMS (3%) caused less injury compared to pyroxasulfone applied POST-directed (9%) at the early timing, thus suggesting it may be a safer alternative for growers considering 5- to 7-leaf POST-directed lay-by applications.

In addition, pyroxasulfone-coated AMS (321 kg ha^{-1}) caused greater injury when applied at the mid timing (4%) compared to the late timing (1%; Table 8). However, regardless of which timing pyroxasulfone-coated AMS (321 kg ha^{-1}) was applied, all injury was ≤ 4% and comparable to the injury observed with non-herbicide treated AMS (321 kg ha^{-1}) applied in the check (≤ 4%). At 14 DA LA, no cotton injury was observed from applications made at the early- or mid-timings (Table 8). It is important to note that by 14 DA LA, 42 and 28 days had elapsed since the early- and mid-timing applications of pyroxasulfone, respectively. These results suggest that there is no adverse cotton response due to these applications being made at different timings. This is further supported by cotton lint yield data, which indicates no differences across all application timings and methods (Table 8).

Practical Implications

Given the complexities of cotton weed management and the continued rise in weed control costs, there is great need for alternative weed management strategies in cotton production. Since being registered in cotton in 2020, limited research has been conducted to optimize pyroxasulfone-coated fertilizer in cotton production systems. This research provides evidence that pyroxasulfone-coated AMS (≥ 214 kg ha^{-1}) has the potential to control Palmer amaranth comparable to pyroxasulfone applied POST and POST-directed, with minimal risk of cotton injury. When applied onto 5- to-7-leaf cotton, pyroxasulfone-coated AMS was less injurious than pyroxasulfone POST-directed; thus, suggesting it may be a safer option for growers considering early-season POST-directed lay-by applications. This research also indicates that when pyroxasulfone is applied to 5- to 7-leaf cotton, an additional POST application may be necessary to achieve season-long control of Palmer amaranth, regardless of the application method. Aside from the results in these studies, it is important that pyroxasulfone-coated AMS be applied in compliance with current label recommendations (Anonymous 2024), as additional research is warranted to further explore the efficacy and usability of pyroxasulfone-coated fertilizer in cotton production. Evaluating its use in the early season may be beneficial, as increased weed pressure at this time could affect weed control.

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Competing Interests

The author(s) declare none.

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Table 1. Dates treatments were applied and accumulated rainfall, Rate Study.[a]

Location	Year	Date	Rainfall			
			0-8 DAT	9-16 DAT	17-24 DAT	25-32 DAT
			--------------------------cm--------------------------------			
Clayton	2022	June 17	0.66	0.59	7.54	0.97
	2023	June 21	3.21	4.52	5.96	0.08
Rocky Mount	2022	June 17	1.6	0.05	6.1	0.46
	2023	June 21	4.52	1.48	8.03	0.23

[a] Abbreviations: DAT, days after treatment

Table 2. Dates treatments were applied at each application timing and accumulated rainfall, Timing Study.[a]

Timing[b]	Location	Year	Date	Rainfall 0-8 DAT	 9-16 DAT	 17-24 DAT	 25-32 DAT
				------------------------------cm	----------------------------		
Early	Clayton	2022	June 10	0.71	0.46	0.97	7.17
		2023	June 21	3.21	4.52	5.96	0.08
	Rocky Mount	2022	June 10	4.09	0.56	0.05	7.21
		2023	June 21	4.52	1.48	8.03	0.23
Mid	Clayton	2022	June 24	0.59	7.55	0.97	0.08
		2023	July 3	6.27	4.65	0.08	0.13
	Rocky Mount	2022	June 24	0.05	7.21	0.47	1.12
		2023	July 3	4.53	5.06	1.12	0.28
Late	Clayton	2022	July 6	7.2	0.94	2.57	0.81
		2023	July 17	0.08	0.13	2.42	4.39
	Rocky Mount	2022	July 6	7.24	0.44	5.11	2.57
		2023	July 17	1.15	0	0.61	3.26

[a] Abbreviations: DAT, days after treatment

[b] Application timings: Early, 5- to 7-leaf; Mid, 9- to 11-leaf; Late, first bloom.

Table 3. Palmer amaranth control and density as influenced by pyroxasulfone applied POST, POST-directed, and coated on differing rates of granular ammonium sulfate fertilizer.[a,b]

Herbicide[c,d]	Treatment[e,f]	AMS rate	Control 42 DAT		Density	
		kg ha^{-1}	%		plants m^{-2}	
None	AMS	321	—		8	a
Pyroxasulfone	AMS	161	79	b	2	b
Pyroxasulfone	AMS	214	83	ab	1	b
Pyroxasulfone	AMS	267	84	ab	2	b
Pyroxasulfone	AMS	321	85	ab	3	b
Pyroxasulfone	AMS	374	88	ab	2	b
Pyroxasulfone	AMS	428	88	ab	1	b
Pyroxasulfone	AMS	481	88	ab	2	b
Pyroxasulfone	POST	321	92	a	2	b
Pyroxasulfone	POST-directed	321	89	ab	2	b

[a] Means followed by the same letter are not different according to Tukey's honestly significant difference at (a = 0.05).

[b] Abbreviations: DAT, days after treatment; POST, postemergence; POST-directed, postemergence-directed; AMS, granular ammonium sulfate.

[c] Pyroxasulfone was applied at 118 g ai ha^{-1}.

[d] Applications were made on 5- to- 7-leaf cotton.

[e] Non-herbicide treated AMS was applied at 321 kg ha^{-1} in the check and where pyroxasulfone was applied POST and POST-directed.

[f] Prior to applications, 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 and yield after pyroxasulfone was applied POST, POST-directed, and coated on differing rates of granular ammonium sulfate fertilizer.[a,b]

			Cotton injury		
Herbicide[c,d]	Treatment[e,f]	AMS rate	3 DAT	14 DAT	Lint yield
		kg ha^{-1}	------------%----------		kg ha^{-1}
None	AMS	321	2 c	3 c	—
Pyroxasulfone	AMS	161	1 c	2 c	1,100 a
Pyroxasulfone	AMS	214	1 c	3 c	1,080 a
Pyroxasulfone	AMS	267	1 c	3 c	1,200 a
Pyroxasulfone	AMS	321	3 c	3 c	1,040 a
Pyroxasulfone	AMS	374	2 c	3 c	1,100 a
Pyroxasulfone	AMS	428	2 c	3 c	1,040 a
Pyroxasulfone	AMS	481	2 c	4 bc	1,130 a
Pyroxasulfone	POST	321	12 a	8 a	1,070 a
Pyroxasulfone	POST-directed	321	7 b	5 b	1,060 a

[a] Means followed by the same letter are not different according to Tukey's honestly significant difference at (a = 0.05).

[b] Abbreviations: DAT, days after treatment; POST, postemergence; POST-directed, postemergence-directed; AMS, granular ammonium sulfate.

[c] Pyroxasulfone was applied at 118 g ai ha^{-1}.

[d] Applications were made onto 5- to 7-leaf cotton.

[e] Non-herbicide treated AMS was applied at 321 kg ha^{-1} in the check and where pyroxasulfone was applied POST and POST-directed.

[f] Prior to applications, 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 5. Analysis of variance for the main effects of application method and timing on cotton injury and Palmer amaranth control.[a]

	Cotton injury		Control		
Source of variation	3 DAT	14 DA LA	42 DAT	Density	Lint yield
	----------------------------------P-value----------------------------------				
Method (M)	<0.001	<0.001	0.916	0.001	0.488
Timing (T)	<0.001	<0.001	<0.001	0.062	0.573
M × T	0.002	<0.001	0.795	0.023	0.931

[a] Abbreviations: DAT, days after treatment; DA LA, days after late applications.

Table 6. Palmer amaranth control and density as influenced by pyroxasulfone applied POST, POST-directed, and coated on granular ammonium sulfate.[a,b]

Herbicide[c]	Method[d,e]	Control 42 DAT	Density	
		%	plants m^{-2}	
None	AMS	-	16	a
Pyroxasulfone	Coated	90	2	b
Pyroxasulfone	POST	91	2	b
Pyroxasulfone	POST-directed	90	2	b

[a] Data are averaged over application timings. Means followed by the same letter are not different according to Tukey's honestly significant difference at (a = 0.05).

[b] Abbreviations: DAT, days after treatment; POST, postemergence; POST-directed, postemergence-directed; AMS, granular ammonium sulfate.

[c] Pyroxasulfone was applied at 118 g ai ha^{-1}.

[d] Non-herbicide treated AMS was applied at 321 kg ha^{-1} in the check and where pyroxasulfone was applied POST and POST-directed.

[e] Prior to treatment applications, 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 7. Influence of application timing on Palmer amaranth control.[a]

Timing[b,c,d,e]	Control 42 DA LA	
	%	
Early (70 DAT)	83	b
Mid (56 DAT)	93	a
Late (42 DAT)	95	a

[a] Data are averaged over application methods. Means followed by the same letter are not different according to Tukey's honestly significant difference at (a = 0.05).

[b] Abbreviations: DAT, days after treatment; DA LA, days after late application.

[c] Application timings: Early, 5- to 7-leaf; Mid, 9- to 11-leaf; Late, first bloom.

[d] Pyroxasulfone (118 g ai ha^{-1}) was applied POST, POST-directed, and coated on granular ammonium sulfate fertilizer (321 kg ha^{-1}) at each timing

Table 8. Cotton injury and yield as influenced by pyroxasulfone applied POST, POST-directed, and coated on granular ammonium sulfate at different application timings.[a,b]

Herbicide[c]	Timing[d]	Method[e,f]	Cotton injury 3 DAT		Cotton injury 14 DA LA		Lint yield	
			---------------%---------------				kg ha^{-1}	
None	Early	AMS	3	ef	0	c	–	
Pyroxasulfone		Coated	3	ef	0	c	1,000	a
Pyroxasulfone		POST	16	a	0	c	1,000	a
Pyroxasulfone		POST-directed	9	b	0	c	1,070	a
None	Mid	AMS	4	de	0	c	–	
Pyroxasulfone		Coated	4	de	0	c	1,060	a
Pyroxasulfone		POST	14	a	0	c	1,050	a
Pyroxasulfone		POST-directed	6	cd	0	c	1,100	a
None	Late	AMS	1	f	1	b	–	
Pyroxasulfone		Coated	1	f	1	b	1,130	a
Pyroxasulfone		POST	8	bc	9	a	1,020	a
Pyroxasulfone		POST-directed	3	ef	1	b	1,110	a

[a] Means followed by the same letter are not different according to Tukey's honestly significant difference at (a = 0.05).

[b] Abbreviations: DAT, days after treatment; DA LA, days after late application; POST, postemergence; POST-directed, postemergence-directed; AMS, granular ammonium sulfate.

[c] Pyroxasulfone was applied at 118 g ai ha^{-1}.

[d] Application timings: Early, 5- to 7-leaf; Mid, 9- to 11-leaf; Late, first bloom.

[e] Non-herbicide treated AMS was applied at 321 kg ha^{-1} in the check and where pyroxasulfone was applied POST and POST-directed.

[f] Prior to applications, all plots (including the check) were treated with glyphosate at 1,345 g ae ha^{-1} and glufosinate at 656 g ai ha^{-1}.