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WEED SCIENCE

Trifloxysulfuron-sodium Application Does Not Provide Season-long Plant Height Control or Hasten Maturity of Cotton (*Gossypium hirsutum* L.)

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ABSTRACT

Trifloxysulfuron-sodium (TFS), an acetolactate synthase-inhibiting herbicide, utilized postemergence in cotton (*Gossypium hirsutum* L.) to control certain broadleaf weeds, has been reported to cause stunting visually similar to mepiquat chloride (MC) application. The objective of this research was to examine cotton response, in multiple environments to POST broadcast application timings and rates of TFS with and without MC, to determine if TFS application alters the need for MC application. Six TFS treatment combinations were evaluated in Virginia and North Carolina in 2005 and 2006, including an untreated check, and a fifth node application (FNA) or eighth node application (ENA) with rates of 5.3 g ai ha^{-1} or 7.9 g ai ha^{-1}, with or without MC. Trifloxysulfuron-sodium application had no influence on plant height, height-to-node ratio, or maturity; however, the number of apical main-stem nodes increased with the FNA compared to untreated cotton. Mepiquat chloride application reduced harvest plant height by 10%, reduced height-to-node ratio by 8%, and hastened maturity as measured by nodes above white flower. Lint yield and lint percentage were not altered by TFS or MC application, while fiber quality results were mainly unaffected. These results suggest that TFS application does not have the season-long effects on plant growth and maturity attributed to a MC application.

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Early season postemergence (POST) broadcast herbicide applications are often utilized in cotton (*Gossypium hirsutum* L.) to control weeds prior to the 12th-true leaf stage. Trifloxysulfuron-sodium (TFS) (Envoke®, Syngenta Crop Protection, Greensboro, NC) (N-[(4,6-Dimethoxy-2-pyrimidinyl)amino] carbonyl-3-(2,2,2-trifluoro-ethoxy)-pyridin-2-sulfonamide sodium salt) is an acetolactate synthase enzyme (ALS, EC 4.1.3.18)-inhibiting, POST broadleaf weed herbicide, which may be utilized after the 5th leaf stage in cotton (Hudetz et al., 2000; Richardson et al., 2004a; Richardson et al., 2007a; Richardson et al., 2007b).

Trifloxysulfuron-sodium application provides 70% or greater control of numerous common broadleaf weeds in cotton including common cocklebur (*Xanthium strumarium* L.), common lambsquarters (*Chenopodium album* L.), common ragweed (*Ambrosia artemisiifolia* L.), entireleaf morningglory (*Ipomoea hederacea* var. *integriuscula* Gray), hemp sesbania [*Sesbania exaltata* (Raf.) Rydb. ex A. W. Hill], ivyleaf morningglory [*Ipomoea hederacea* (L.) Jacq.], palmer amaranth (*Amaranthus palmeri* S. Wats.), pitted morningglory (*Ipomoea lacunosa* L.), redroot pigweed (*Amaranthus retroflexus* L.), tall morningglory [*Ipomoea purpurea* (L.) Roth], sicklepod [*Senna obtusifolia* L.) Irwin & Barneby], as well as yellow nutsedge (*Cyperus esculentus* L.) (Branson et al., 2005; Porterfield et al., 2002a; Richardson et al., 2003a; Richardson et al., 2007b). Hudetz et al. (2000) and Troxler et al. (2003) reported that TFS application also resulted in the suppression of other problematic weeds including johnsongrass [*Sorghum halepense* (L.) Pers.] and purple nutsedge (*Cyperus rotundus* L.), however TFS has been unsuccessful in controlling several annual grass species, jimsonweed (*Datura stramonium* L.), prickly sida (*Sida spinosa* L.), smallflower morningglory [*Jacquemontia tamnifolia* (L.) Griseb.], spurred anoda [*Anoda cristata* (L.) Schlecht.], and velvetleaf (*Abutilon theophrasti* Medicus) (Brecke and Stephenson, 2006; Porterfield et al., 2003; Troxler et al., 2003; Richardson et al., 2006). Mixtures of TFS with other POST herbicides including bromoxynil, glyphosate, and pyrithiobac have been reported to increase the control of some of these less susceptible weeds, while complementing the weed control already demonstrated by these herbicides (Branson et al., 2005; Porterfield et al., 2003; Richardson et al., 2004b; Thomas et al., 2006).

Visual cotton injury has been observed after early season POST TFS application as chlorosis of the treated foliage, stunting, and occasional necrotic lesions, which is typical of ALS-inhibiting herbicides (Koger et al., 2005; Richardson et al., 2004a; Richardson et al., 2004b; Thomas et al., 2006). Trifloxysulfuron-sodium applications to cotton POST at the 2 to 4 true leaf stage caused injury ranging from 6 to 67% at one week after treatment (WAT) (Branson et al., 2002; Porterfield et al., 2002a; Richardson et al., 2006; Richardson et al., 2007a), while applications made after the 4^{th} true leaf stage resulted in injury ranging from 0 to 24% at one WAT (Branson et al., 2005; Koger et al., 2005; Porterfield et al., 2002a; Richardson et al., 2006). The injury associated with TFS may be increased by applications made to early plantings during cool, wet weather, but is usually transient with little to no visual symptoms three to four WAT (Crooks et al., 2003; Porterfield et al., 2002a; Porterfield et al., 2002b; Richardson et al., 2003b).

Stunting due to POST TFS application has been reported as a decrease in plant height within one to two WAT (Collins et al., 2007; Hoffman and Cothren, 2002; Richardson et al., 2004a; Thomas et al., 2006). However, Richardson et al. (2004a) reported that stunted plant heights were not significantly different from untreated cotton at eight WAT. Collins et al. (2007) concluded that TFS reduces height-to-node ratio (HNR), sympodial boll retention, and may delay crop maturity. Casteel et al. (2004) reported that TFS application did not influence end of season plant height, main-stem nodes, HNR, or first and outer position boll retention. Cotton lint yields and fiber quality properties have generally been unaffected by single TFS applications when compared to other herbicides, or untreated weed-free treatments (Richardson et al., 2003b; Richardson et al., 2004a; Richardson et al., 2007a; Richardson et al., 2007b). However, Casteel et al. (2004) reported a yield reduction with TFS application on 9 to 10 leaf cotton compared to untreated cotton, while Koger et al. (2005) reported that sequential POST over-the-top TFS applications may reduce yields.

Mepiquat-type plant growth regulators (PGR) are routinely applied in cotton to reduce vegetative growth by decreasing main-stem and sympodial branch internode lengths (Cathey and Meredith, 1988; Collins et al., 2007; Gwathmey and Craig, 2003; Kerby, 1985), and hasten maturity through a reduction in vegetative growth, shifting plant resources to reproductive growth (Cathey and Meredith, 1988; Gwathmey and Craig, 2003; Zhao and Oosterhuis, 2000). Plant growth regulator application decreases gibberellic acid concentration within plant cells, thereby reducing cell wall plasticity (Behringer et al., 1990; Potter and Fry, 1993; Yang et al., 1996). Collins et al. (2007) suggested that a reduction in PGR application rates may be necessary when used in conjunction with TFS to avoid excessive vegetative control and possible yield reduction. The reported reduction of plant height associated with TFS application may alter the need for early season PGR application.

There has been limited research published examining the interaction of TFS and MC application on cotton (Casteel et al., 2004; Collins et al., 2007). This research has suggested that TFS application may cause stunting or other injury to cotton, therefore leading to a reduction in the need for MC applications to avoid excessive growth suppression and yield losses (Casteel et al., 2004; Collins et al., 2007). The objective of this research was to examine cotton response to multiple timings and rates of POST broadcast applications of TFS with and without MC application.

MATERIALS AND METHODS

In 2005 and 2006, field experiments were conducted at the Virginia Tech Tidewater Agricultural Research and Extension Center in Suffolk, VA (36°41' N, 76°46' W) on a Nansemond fine sandy loam (coarse-loamy, siliceous, subactive, thermic Aquic Hapludults), and at the North Carolina State University Upper Coastal Plain Research Station near Rocky Mount, NC (35°54' N, 77°43' W) on a Goldsboro loamy sand (fine-loamy, siliceous, subactive, thermic Aquic Paleudults).

Seven treatment combinations were examined in a randomized complete block design with three replications in Virginia in 2005, and four replications in Virginia in 2006 and North Carolina in 2005 and 2006. Plots consisted of four 12.2-m long rows spaced on 91.4-cm centers. Cultivar Deltapine 444 BG/RR was planted in Virginia and North Carolina during both years. The treatments consisted of an untreated check and six combinations of TFS rates and timings in the presence or absence of mepiquat chloride (MC) (Pix® Plus Plant Regulator, BASF, Research Triangle Park, NC). The treatment combinations were: 1) 5.3 g ai ha^{-1}

of TFS applied at the 8th node growth stage and 24.4 g ai ha^{-1} of MC applied at early bloom; 2) 7.9 g ai ha^{-1} of TFS applied at the 8th node growth stage and 24.4 g ai ha^{-1} of MC applied at early bloom; 3) 5.3 g ai ha^{-1} of TFS applied at the 5th node growth stage and 24.4 g ai ha^{-1} of MC applied at early bloom; 4) 7.9 g ai ha^{-1} of TFS applied at the 5th node growth stage and 24.4 g ai ha^{-1} of MC applied at early bloom; 5) 7.9 g ai ha^{-1} of TFS applied at the 8th node growth stage; and 6) 7.9 g ai ha^{-1} of TFS applied at the 5th node growth stage. A nonionic surfactant (Induce®, Helena Chemical Company, Collierville, TN) was included with each of the TFS treatments at 0.25% v/v. Decisions on fertility, late season weed control, and insect control were followed according to respective state cooperative extension recommendations (Edmisten et al., 2005; Faircloth et al., 2005).

All data were collected from the center two rows of the plots including in-season plant heights (2 to 3 WAT and at harvest), nodes above white flower (NAWF) (early-August), lint yield, and fiber quality. Due to excessively rank growth in Virginia in 2005, a late season MC application was applied to the untreated cotton, therefore only the two to three WAT plant height is reported for growth characteristics in that year. In North Carolina in 2005, the two to three WAT and NAWF measurements were not collected for the untreated cotton, therefore those measurements were not included in the results.

Plant mapping data were collected from six randomly selected plants within each treatment at the end of the growing season in Virginia and North Carolina in 2005 and 2006 to determine the number of apical main-stem (AMS) nodes, HNR, total number of monopodial bolls, first sympodial node, first and second fruiting position sympodial bolls, total number of bolls, percent retention of first and second fruiting position sympodial bolls, and boll distribution by nodal zone (Bourland and Watson, 1990). Only the number of AMS nodes and HNR are reported due to minimal differences in all other plant mapping data.

Defoliant was applied uniformly across all treatments. The center two rows of each four-row plot were harvested approximately two weeks later using a two-row commercial spindle cotton harvester. Seed-cotton samples from each plot were retained and ginned on a 10-saw gin to determine lint yield. A sub-sample was sent to the USDA classing office in Florence, SC to determine physical fiber properties using a high volume instrument analysis (USDA AMS Cotton Program Florence South Carolina Classing Office, Florence, SC).

Using PROC GLM (SAS Institute, 2000), a mixed model analysis of variance was carried out on the combined data from two years and two locations (year × location effect is listed as a single random factor "trial"), with trial, replication within trial, and trial × treatment effects viewed as random factors. Contrasts for specific hypotheses were used to evaluate the significance of TFS application rates and timings, along with MC application (Table 1). There were no significant trial × treatment interactions and results are presented as means over both years and locations. Statistical significance was evaluated at P = 0.05.

Table 1. Trifloxysulfuron-sodium and mepiquat chloride application contrasts analyzed for Virginia and North Carolina (2005 and 2006).

Contrast	Name	TFS application timing [z]	TFS application rate	MC application
1	TFS w/ MC	5th and 8th node	7.9 g ai ha^{-1}	Yes
	TFS w/o MC	5th and 8th node	7.9 g ai ha^{-1}	No
2	TFS 5.3 g ai ha^{-1}	5th and 8th node	5.3 g ai ha^{-1}	Yes
	TFS 7.9 g ai ha^{-1}	5th and 8th node	7.9 g ai ha^{-1}	Yes
3	FNA Avr.	5th node	5.3 and 7.9 g ai ha^{-1}	Yes
	ENA Avr.	8th node	5.3 and 7.9 g ai ha^{-1}	Yes
4	FNA 5.3 g ai ha^{-1}/ ENA 7.9 g ai ha^{-1}	5th and 8th node	5.3 and 7.9 g ai ha^{-1}	Yes
	FNA 7.9 g ai ha^{-1}/ ENA 5.3 g ai ha^{-1}	5th and 8th node	7.9 and 5.3 g ai ha^{-1}	Yes
5	Non-treated	-	-	No
	FNA 7.9 g ai ha^{-1}	5th node	7.9 g ai ha^{-1}	No
6	Non-treated	-	-	No
	ENA 7.9 g ai ha^{-1}	8th node	7.9 g ai ha^{-1}	No

[z] Abbreviations: ENA (eighth node application); FNA (fifth node application); MC (mepiquat chloride); TFS (trifloxysulfuron-sodium)

RESULTS AND DISCUSSION

Environmental Conditions: Total heat unit accumulation from planting to harvest in 2005 and 2006 in Virginia was 1309 and 1135 units with total precipitation of 53.3 and 82.7 cm, while North Carolina accumulated 1374 and 1237 units with total precipitation of 43.5 and 83.4 cm, respectively. Based on these two variables, the environmental conditions were relatively similar for Virginia and North Carolina in 2005 and 2006, although North Carolina accumulated slightly more heat units each year (65 and 102 units, respectively).

Previous researchers have suggested that stunting and discoloration in cotton following TFS application may be enhanced by environmental conditions shortly before and following application (Branson et al., 2002; Branson et al. 2005; Richardson et al., 2003b; Richardson et al., 2007b). These conditions include cool temperatures and/or moisture-saturated soils, which may slow the metabolism of TFS in cotton (Askew and Wilcut, 2002; Branson et al., 2002; Branson et al., 2005; Richardson et al., 2007b). During the five day time span of two days before through two days after application in all trials, the total heat unit accumulation ranged from 29.1 to 49.1, while the total precipitation accumulation ranged from 0.0 to 2.32 cm (Table 2). Since there were no significant trial × treatment interactions, the environmental conditions just prior and after application did not seem to alter the cotton growth characteristics measured.

Growth Characteristics: Previous research has reported that TFS causes a decrease in plant height of 7 to 20% compared to untreated cotton (Casteel et al., 2004; Collins et al., 2007; Richardson et al., 2004a; Richardson et al., 2007a). In this research, TFS application timings and rates had no influence on plant height measurements taken at two to three WAT in Virginia or North Carolina (data not shown). Plant height at harvest was also not influenced by TFS application in this research (Table 3). In contrast, Collins et al. (2007) reported that TFS decreased end of season plant height by 5%.

Mepiquat chloride application resulted in a 10% reduction in plant height at harvest compared to cotton that did not receive MC (Table 3). Measurable end of season plant height reduction following MC

Table 2. Heat unit and precipitation accumulation for the two days before, day of, and two days after each application in Virginia and North Carolina (2005 and 2006).

Location	Application timing	2 days before	1 day before	Day of application	1 day after	2 days after	Total
		Heat unit accumulation					
VA (2005)	5th node	13.3	11.9	9.5	6.5	6.1	47.3
	8th node	4.1	8.9	7.8	8.8	8.2	37.8
VA (2006)	5th node	8.9	10.8	10.3	8.4	7.7	46.1
	8th node	5.4	5.8	7.7	10.5	11.4	40.8
NC (2005)	5th node	9.5	9.6	10.0	8.6	10.2	47.9
	8th node	3.6	5.0	9.6	9.2	8.3	35.7
NC (2006)	5th node	8.7	6.4	3.2	4.0	6.8	29.1
	8th node	9.8	8.4	10.9	10.6	9.3	49.0
		Precipitation accumulation					
VA (2005)	5th node	0	0	0	0	0	0
	8th node	0	0	0	0	0	0
VA (2006)	5th node	1.45	0	0	0	0	1.45
	8th node	0	0	0	0	0	0
NC (2005)	5th node	0.03	0	2.29	0	0	2.32
	8th node	0	0	0	0	0	0
NC (2006)	5th node	0.03	0	0.03	0.03	0.10	0.19
	8th node	0	0.03	0.10	0	0	0.13

application is reported repeatedly in the literature (Casteel et al., 2004; Collins et al., 2007; Gwathmey and Craig, 2003; Siebert and Stewart, 2006).

Similar to Casteel et al. (2004), TFS timing and rate of application had no influence on HNR in this experiment (Table 3). In contrast, Collins et al. (2007) reported that TFS application reduced HNR by 10%. Mepiquat chloride application decreased the HNR by 8%, which is consistent with research by Collins et al. (2007), Nuti et al. (2006), and Siebert and Stewart (2006).

Although plant height and HNR were not influenced by TFS application, the number of AMS nodes was increased by approximately one node plant^{-1} with the FNA of TFS when compared to untreated cotton (Table 3). The ENA of TFS trended toward more nodes than the untreated cotton; however this value was not significant. Mepiquat chloride application decreased the number of AMS nodes plant^{-1} by 0.5, which is similar to reported decreases of 0.7 to 2.0 nodes plant^{-1} by Kerby (1985), Nichols et al. (2003), and Nuti et al. (2006).

Richardson et al. (2004a) and Richardson et al. (2007b) have suggested that TFS application may delay maturity based on a lower number of white and pink flowers plant^{-1} when counted at three to five days after first flower in TFS treated cotton. However, TFS application timings and rates had no influence on maturity based on NAWF in this experiment (Table 3). Consistent with previous research by Cathey and Meredith (1988), Coccaro et al. (2003), Gwathmey and Craig (2003), and York (1983), MC application hastened maturity based on NAWF relative to cotton that did not receive MC.

Table 3: Trifloxysulfuron-sodium application timing and rate and mepiquat chloride application effect on harvest plant height, height-to-node ratio, apical main-stem nodes, nodes above white flower, lint yield, micronaire, and fiber strength for Virginia and North Carolina (2005 and 2006).

Contrasts	Harvest plant height [z]	Height-to-node ratio	Apical main-stem nodes	NAWF [y]	Lint yield	Micronaire	Fiber strength
	—— cm ——		—— no. plant^{-1} ——		kg ha^{-1}	units	g tex^{-1}
TFS w/ MC	69	4.6	15.5	2.5	1216	4.6	30.1
TFS w/o MC	77	5.0	16.0	3.1	1207	4.5	29.5
Contrast (Pr>F)	0.0004	0.0012	0.0191	0.0008	NS	0.0122	0.0275
TFS 5.3 g ai ha^{-1}	69	4.5	15.6	2.5	1258	4.5	29.5
TFS 7.9 g ai ha^{-1}	69	4.6	15.5	2.5	1216	4.6	30.1
Contrast (Pr>F)	NS	NS	NS	NS	NS	NS	NS
FNA Avr.[x]	74	4.8	15.8	2.9	1198	4.6	29.7
ENA Avr.	72	4.8	15.6	2.8	1224	4.5	29.8
Contrast (Pr>F)	NS	NS	NS	NS	NS	NS	NS
FNA 5.3 g ai ha^{-1} + ENA 7.9 g ai ha^{-1}	68	4.5	15.6	2.6	1242	4.5	29.9
FNA 7.9 g ai ha^{-1} + ENA 5.3 g ai ha^{-1}	70	4.6	15.6	2.5	1232	4.5	29.6
Contrast (Pr>F)	NS	NS	NS	NS	NS	NS	NS
Non-treated	76	5.1	15.2	3.5	1274	4.6	29.4
FNA 7.9 g ai ha^{-1}	78	5.0	16.1	3.8	1213	4.5	29.6
Contrast (Pr>F)	NS	NS	0.0089	NS	NS	NS	NS
Non-treated	76	5.1	15.2	3.5	1274	4.6	29.4
ENA 7.9 g ai ha^{-1}	76	5.0	15.8	3.6	1200	4.6	29.3
Contrast (Pr>F)	NS	NS	NS	NS	NS	NS	NS

[z] Results for contrasts 1-4 are based on Virginia (2006) and North Carolina (2005 and 2006), while contrasts 5-6 are based on Virginia (2006) and North Carolina (2006).

[y] Abbreviations: ENA (eighth node application); FNA (fifth node application); MC (mepiquat chloride); NAWF (nodes above white flower); TFS (trifloxysulfuron-sodium)

[x] FNA at 5.3 g ai ha^{-1} and 7.9 g ai ha^{-1} with MC versus ENA at 5.3 g ai ha^{-1} and 7.9 g ai ha^{-1} with MC.

Lint Yield, Percentage, and Fiber Quality: Lint yield was not influenced by TFS treatment rates and timings in either year in Virginia or North Carolina (Table 3). Similar to lint yield data, lint percentage, micronaire, fiber length, fiber strength, and fiber length uniformity were not influenced by TFS application timings and rates (data not shown). Previous research in Virginia also concluded that label TFS application timings and rates on cotton has no influence on lint yield or fiber quality properties (Richardson et al., 2003b; Richardson et al., 2004a; Richardson et al., 2004b; Richardson et al., 2007b), however Collins et al. (2007) has reported a 7% yield reduction with TFS application in North Carolina. It may be possible that lint yield and fiber quality were not affected by TFS application in this research due to similar environmental conditions that occurred during the growing season in Virginia and North Carolina.

While MC application impacted all growth characteristics and hastened maturity, there was no effect on lint yield (Table 3), lint percentage, fiber length, or fiber length uniformity (data not shown). Similar results were reported by Siebert and Stewart (2006). However, micronaire and fiber strength were influenced by MC application, where both micronaire and fiber strength values increased in treatments that included MC compared to cotton not treated with MC. The increase in micronaire is consistent with previous research by Kerby (1985) and Siebert and Stewart (2006), while Cathey and Meredith (1988), Kerby (1985), and Nuti et al. (2006) have all reported an increase in fiber strength with MC application.

CONCLUSIONS

Environmental conditions during certain years may enhance cotton growth response to TFS application (Branson et al., 2002; Branson et al. 2005; Richardson et al., 2003b; Richardson et al., 2007b); however based on the findings of this experiment, there were no abnormal effects caused by the heat unit or precipitation accumulation near application timing. While it has been previously reported that plant height at two to three WAT can be reduced in certain years following TFS application, plant height at harvest does not seem to be significantly influenced by TFS applications as seen in this experiment. In contrast, MC application frequently reduces harvest plant height. Additionally, TFS application does not appear to impact maturity or HNR as compared to MC application. Thus, TFS application should not be expected to elicit similar responses as MC application. Lint yield and fiber quality properties were also unaffected by TFS application, therefore following label application timings and rates should not result in adverse effects on yield and quality. The differences in micronaire and fiber strength due to MC application correspond with the frequent inconsistency in fiber quality.

Since our findings are limited to only two locations and two years, further research should be conducted to examine additional TFS application timings and rates compared to MC application in controlled and variable environmental conditions. In conclusion, TFS application may temporarily influence cotton growth in certain years; however the response is negligible at harvest and does not warrant reducing MC application for full-season vegetative growth control or to hasten maturity.

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