From Forest Nursery Notes, Summer 2009

215. Purple and yellow nutsedge (*Cyperus rotundus* and *C. esculentus*) response to postemergence herbicides in cotton. Burke, I. C., Troxler, S. C., Wilcut, J. W., and Smith, W. D. Weed Technology 22:615-621. 2008.

Weed Technology 2008 22:615–621

Purple and Yellow Nutsedge (*Cyperus rotundus* and *C. esculentus*) Response to Postemergence Herbicides in Cotton

Ian C. Burke, Shawn C. Troxler, John W. Wilcut, and W. David Smith*

Greenhouse studies were conducted to evaluate the nature of the cotton postemergence (POST) herbicides followed by (fb) MSMA postemergence-directed (LAYBY) for foliar and tuber reduction of yellow and purple nutsedge when applied to nutsedge at two different application timings. Trifloxysulfuron at 4 and 6 g ai/ha fb MSMA LAYBY reduced 10- to 15- and 20- to 30-cm purple and yellow nutsedge root and shoot dry weights by at least 56%. However, the effect of weed size at the time of application was significant for trifloxysulfuron at 6 g/ha for percent root and shoot reductions in yellow nutsedge and percent root reduction in purple nutsedge. Significance of herbicide rate was only observed for percent shoot and root reduction of 10- to 15-cm yellow nutsedge. Trifloxysulfuron treatments reduced purple and yellow nutsedge shoot and root dry weights equivalent to treatments involving glyphosate POST fb MSMA LAYBY. MSMA at 1,120 and 2,240 g/ha and glufosinate POST fb MSMA LAYBY were effective for reducing purple and yellow nutsedge shoot dry weights, although percent reduction was influenced by nutsedge height at herbicide application. Treatments involving pyrithiobac POST fb MSMA LAYBY slightly increased 10- to 15-cm yellow nutsedge root dry weights. MSMA at either rate produced additive responses when included in tank mixtures with trifloxysulfuron at either rate or pyrithiobac POST fb MSMA LAYBY in yellow nutsedge. Other tank mixes or sequential combinations did not cause additive or synergistic responses.

Nomenclature: Glufosinate; glyphosate; MSMA; pyrithiobac; trifloxysulfuron; purple nutsedge, *Cyperus rotundus* L. CYPRO; yellow nutsedge, *Cyperus esculentus* L. CYPES; cotton, *Gossypium hirsutum* L.
Key words: Glufosinate, glyphosate, pyrithiobac, herbicide-resistant crops, LAYBY, MSMA, trifloxysulfuron.

Purple and yellow nutsedge are some of the most troublesome and common weeds in cotton in the southeastern United States (Dowler 1998). Cotton producers have few options for selective control of perennial nutsedges (Wilcut et al. 1995). In the past, cotton growers have relied on a program of norflurazon-applied preplant incorporated (PPI), coupled with several postemergence-directed (LAYBY) applications of DSMA, or MSMA (Wilcut et al. 1995) for control of nutsedge species. At rates labeled for perennial nutsedge control in cotton, growers cannot apply DMSA and MSMA postemergence over-the-top (POT) due to potential for maturity delay and yield reduction (Shankle et al. 1996). However, the perennial nature of nutsedge spp. (Stoller and Sweet 1987), as well as the vigorous growth of the weed at the time of cotton emergence, makes postdirected (PD) applications difficult. The slow and laborious nature of PD applications cause many cotton growers to prefer a POT herbicide option for effective early season weed control (Wilcut et al. 1996). Prior to 1995, cotton growers had no options for POT control of nutsedge species and annual broadleaf weeds (Burke and Wilcut 2004; Dotray et al. 1996).

In the last decade, development and registration of new POST herbicides by either traditional herbicide development or with the development of genetically modified herbicide-resistant cotton has expanded the postemergence options for selective nutsedge control. Pyrithiobac was registered in 1995 for POST application in cotton for the selective control of several broadleaf weeds (Dotray et al. 1996; Jordan et al. 1993; Shankle et al. 1996; Webster et al. 2000). Although pyrithiobac has activity on nutsedge, previous research has shown control to be inconsistent (Ackley et al.1996; Wilcut 1998).

Trifloxysulfuron is a POST herbicide developed for use in cotton, sugarcane (*Saccharum* spp.), turfgrass, and tomato (*Solanum lycopersicum* L.) (Butler et al. 2006; Porterfield et al. 2002). Trifloxysulfuron is effective on many difficult-to-control weeds in cotton, including common cocklebur (*Xanthium strumarium* L.), sicklepod [*Senna obtusifolia* (L. H. S. Irwin & Barneby], morningglory (*Ipomoea* spp.), and hemp sesbania (*Sesbania exalta* Raf.) (Brecke and Stephenson 2006; Burke et al. 2005; Burke and Wilcut 2004; Koger et al. 2005; Richardson et al. 2004). Control of perennial nutsedge with trifloxysulfuron has been observed in several crops and environments (Burke and Wilcut 2004; Butler et al. 2006; Singh and Singh 2004.). Due to injury concerns, trifloxysulfuron can only be applied after cotton has five leaves. However, nutsedge control is often needed well before crop development is sufficient for trifloxysulfuron application (Butler et al. 2006; Porterfield et al. 2002).

The development of herbicide-resistant cotton cultivars has provided new opportunities for nutsedge management in cotton. Glyphosate and glufosinate are nonselective herbicides that control numerous grass and broadleaf weeds in cotton (Askew and Wilcut 1999; Culpepper and York 1999). Glyphosate controls purple and yellow nutsedge (Corbett et al. 2004; Keeley et al. 1985; Rao and Reddy 1999), but timing of application is critical for maximum control (Corbet et al. 2004; Doll and Piedrahita 1982; Jordan et al. 1997; Tharp and Kells 1999). Glufosinate can control annual and perennial weeds in glufosinate-resistant cotton (Corbett et al. 2004) and can cause injury to perennial nutsedges (Nelson et al. 2002).

DOI: 10.1614/WT-07-183.1

* First author: Assistant Professor, Crop and Soil Science Department, Box 64620, Washington State University, Pullman, WA 99163; second, third, and fourth authors: Former Graduate Research Assistant, Professor, and Professor, Crop Science Department, Box 7620, North Carolina State University, Raleigh, NC 27695-7620. Corresponding author's E-mail: icburke@wsu.edu

The objectives of this study were to evaluate and characterize the nature of trifloxysulfuron, glyphosate, glufosinate, MSMA, pyrithiobac, and tank mixtures for foliar and tuber reduction of yellow and purple nutsedge at two different application timings.

Materials and Methods

Greenhouse experiments were conducted during the fall of 2000 and the summer of 2001 at the Weed Science Research Unit, in Raleigh, NC. Purple and yellow nutsedge tubers were obtained from a commercial source[1] and five tubers were planted in 15-cm-diam pots containing a Dothan loamy sand (fine-loamy, siliceous, thermic Kandiudults). After emergence, nutsedge plants were thinned to three uniform plants per pot. Greenhouse conditions were kept at 30/22 (± 3 C) day/night temperature with a normal diurnal photoperiod. Nutsedge plants were watered as needed for optimum growth. Fertilizer[2] was supplied to all pots on a weekly basis beginning 2 wk after planting.

Treatment structure consisted of a split-plot arrangement in a randomized complete block design with four replications of treatments. Main plots included either two purple or yellow nutsedge herbicide application timings, at (10- to 15-cm and 20- to 30-cm nutsedge heights), and subplots consisted of 28 herbicide treatments. The treatments consisted of a nontreated control, trifloxysulfuron at 4 g ai/ha or 6 g/ha, glyphosate at 1,120 g ae/ha, glufosinate at 400 g ai/ha, pyrithiobac at 36 g ai/ha, and MSMA at 1,120 g ai/ha or 2,240 g/ha, and all possible two-way combinations thereof. Nonionic surfactant[3] (0.25% v/v) was included with all treatments that included pyrithiobac or trifloxysulfuron. Spray solutions were applied using an indoor spray chamber calibrated to supply 190 L/ha at 146 kPa. After spraying, plants were returned to the greenhouse and watered as needed. Care was taken to direct water away from the nutsedge foliage for 4 d after treatment. Thirty days after treatment (DAT), MSMA at 2,240 g ai/ha was applied to the entire experiment using an indoor spray chamber calibrated to supply 190 L/ha at 146 kPa to simulate the normal LAYBY application that cotton growers employ for late season weed control, especially for nutsedge management. Nutsedge shoots were clipped at the soil surface 30 d after MSMA LAYBY application and dried 72 h at 35 C. Nutsedge roots and tubers were then washed free of soil and dried for the same duration and temperature as the shoots.

Separate studies for yellow and purple nutsedge were conducted, each study consisting of two trial runs repeated in time. Data for each study were transformed to percent weight reduction relative to the nontreated. Analysis of variance revealed no significant trial interaction, and data were combined over trials for analysis and presentation. Means were separated with the use of Fisher's protected LSD test at $P \leq 0.05$.

Results and Discussion

Purple Nutsedge. No statistical difference was observed between trials, thus data were pooled. Both the main-plot effect of herbicide application timing and herbicide treatment were significant; therefore, data are presented by timing and treatment.

Shoots. No significant treatment differences were observed to reduce percent shoot dry weight of purple nutsedge at 10- to 15-cm height (Table 1), although numerical differences existed. The cotton POST herbicides fb MSMA LAYBY application alone reduced purple nutsedge shoot weight by at least 42 percent, regardless of the herbicide treatment.

A MSMA LAYBY treatment without POST herbicides reduced 20- to 30-cm purple nutsedge shoot dry weight by 32% (Table 1). Hamilton (1971) observed a 37% reduction in the number of shoots per plant resulting from a single application of MSMA. The addition of trifloxysulfuron as a POST treatment fb MSMA LAYBY was more effective than MSMA LAYBY alone. Percent shoot dry weight reduction was at least 73% in 20- to 30-cm purple nutsedge, whereas percent shoot dry weight reduction was not affected by MSMA rate. Percent shoot dry weight reduction by trifloxysulfuron fb MSMA LAYBY was equivalent to glyphosate POST fb MSMA LAYBY, which also reduced shoot dry weights 73%. MSMA applied POST fb MSMA LAYBY reduced 20- to 30-cm purple nutsedge shoot dry weights by 53%, regardless of herbicide rate. Pyrithiobac POST fb MSMA LAYBY reduced purple nutsedge growth. The percent shoot dry weight growth reduction was 17% greater when pyrithiobac was applied POST fb MSMA LAYBY compared to MSMA LAYBY alone. Wilcut (1998) observed that pyrithiobac was only marginally effective at reducing emerged purple nutsedge shoots, resulting in a 20% shoot reduction 30 DAT. Glufosinate POST fb MSMA LAYBY reduced shoot dry weight 46%. Although glufosinate application causes leaf burn, nutsedge control rarely approaches acceptable levels (Nelson et al. 2002). Differential tolerance of weed species to glufosinate was attributed to variable absorption and translocation among species (Mersey et al. 1990; Steckel et al. 1997). Percent shoot growth reduction was 46% with glufosinate POST fb MSMA LAYBY and the addition of pyrithiobac to glufosinate in a tank mixture POST fb MSMA LAYBY was 66%. All other herbicide combinations did not produce additive responses in percent shoot dry weight reduction in 20- to 30-cm purple nutsedge. The addition of MSMA at 1,120 g/ha to glyphosate in a tank mixture POST fb MSMA LAYBY produced an antagonistic response, reducing percent shoot dry weight reduction by 14% compared to glyphosate POST alone. Percent shoot dry weight reduction was also less at the 20- to 30-cm purple nutsedge height than at the 10- to 15-cm height when such a herbicide program was included. Koger et al. (2007) have documented antagonism of glyphosate activity on several weed species by MSMA. Glyphosate plus pyrithiobac POST fb MSMA LAYBY reduced purple nutsedge shoot dry weight 24% when it was applied at later timing. Rao and Reddy (1999) observed that glyphosate plus pyrithiobac POST in a tank mixture produced antagonistic responses in 3-wk-old purple nutsedge. Observed decrease in percent shoot dry weight reduction could be due to differential absorption and translocation of these herbicides in older plants.

Roots/Tubers. Trifloxysulfuron POST fb MSMA LAYBY reduced 10- to 15-cm purple nutsedge root/tuber dry weight by at least 73%, and reduction was not influenced by herbicide rate (Table 1). Similar results involving the root/

Table 1. Percent shoot and root/tuber dry weight reduction of 10- to 15-cm and 20- to 30-cm purple nutsedge resulting from the application of cotton postemergence herbicides (60 DAT).[a] All treatments received a LAYBY application of MSMA at 2,240 g ai/ha 30 DAT.

		10 to 15 cm		20 to 30 cm	
		Shoot	Root/tuber	Shoot	Root/tuber
Postemergence herbicide		dry weight	dry weight	dry weight	dry weight
	g ai or g ae/ha[b]	% reduction			
No POST	—	42	35	32	26
Trifloxysulfuron	4	79	73	73	56
Trifloxysulfuron	5	77	77	78	55*[c]
Glyphosate	1,120	65	62	73	67
Glufosinate	400	63	46	46	48
MSMA	1,120	50	52	53	49
MSMA	2,240	62	63	53	67
Pyrithiobac	36	64	44	49	41
Trifloxysulfuron + glyphosate	4 + 1,120	66	62	67	61
Trifloxysulfuron + glufosinate	4 + 400	80	73	69*	58
Trifloxysulfuron + MSMA	4 + 1,120	74	69	66	68
Trifloxysulfuron MSMA	4 + 2,240	75	73	61*	58*
Trifloxysulfuron + pyrithiobac	4 + 36	67	62	68	49
Trifloxysulfuron + glyphosate	6 + 1,120	77	74	74	66
Trifloxysulfuron + glufosinate	6 + 400	77	66	74	56
Trifloxysulfuron + MSMA	6 + 1,120	65	67	68	62
Trifloxysulfuron + MSMA	4 + 2,240	71	65	78	69
Trifloxysulfuron + pyrithiobac	6 + 36	84	72	71*	62
Glyphosate + glufosinate	1,120 + 400	73	55	67	62
Glyphosate + MSMA	1,120 + 1,120	78	70	59*	66
Glyphosate + MSMA	1,120 + 2,240	71	64	66	65
Glyphosate + pyrithiobac	1,120 + 36	87	76	63*	56*
Glufosinate + MSMA	400 + 1,120	60	57	53*	43
Glufosinate + MSMA	400 + 2,240	69	63	41*	46
Glufosinate + pyrithiobac	400 + 36	75	68	66	57
Pyrithiobac + MSMA	36 + 1,120	58	67	51	40*
Pyrithiobac + MSMA	36 + 2,240	66	78	60	68
LSD (0.05)		NS	15	12	NS

[a] Percent reduction compared to the nontreated control.

[b] Glyphosate rates are g ae/ha.

[c] * Indicates herbicide treatment significance between heights of application.

tuber reduction of purple nutsedge were observed in other experiments involving imidazolinone and sulfonylurea herbicides (Richburg et al. 1993; Vencill et al. 1995). Recent studies have shown that trifloxysulfuron provides good to excellent (> 80%) control of purple nutsedge (Burke and Wilcut 2004; Butler et al. 2006; Singh and Singh 2004). Troxler et al. (2003) reported less than 4% of applied trifloxysulfuron was found in the roots/tubers of purple or yellow nutsedge. Increasing the absorption/translocation of trifloxysulfuron to the roots and tubers could improve purple or yellow nutsedge control and further reduce root and tuber weights.

Glyphosate POST fb MSMA LAYBY reduced 10- to 15-cm purple nutsedge root/tuber dry weight by 62%. Past research has shown that glyphosate is effective for purple nutsedge control and tuber reduction (Akin and Shaw 2001; Corbet et al. 2004; Rao and Reddy 1999); however, multiple applications are necessary for complete (100%) control. Multiple applications of MSMA, as a POST and LAYBY treatment, reduced purple nutsedge root/tuber dry weight at least 52% with no difference in rate of application. Several studies have noted multiple applications of MSMA increased control of purple nutsedge (Brecke et al. 2005; Edenfield et al. 2005). Glufosinate POST fb MSMA LAYBY and pyrithiobac POST fb MSMA LAYBY reduced purple nutsedge root dry weights by 46 and 44%, respectively. Similar results were observed when pyrithiobac was applied POST alone (Wilcut 1998). The addition of MSMA at 2,240 g/ha in a tank mixture with glufosinate increased root/tuber dry weight reduction by 17%. MSMA alone or MSMA plus pyrithiobac reduced root/tuber dry weights similarly.

No significant herbicide treatment effect was observed for percent root/tuber dry weight reduction of 20- to 30-cm purple nutsedge. Purple nutsedge height at application influenced percent root/tuber dry weight reduction of trifloxysulfuron at 6 g/ha POST fb MSMA, with 20- to 30-cm purple nutsedge having 22% less root reduction than 10- to 15-cm plants. Steckel et al. (1997) noted that leaf age and developmental stage of plants influences herbicide absorption and metabolism. No significant glyphosate treatment by application height interaction occurred in this study; however, previous studies have noted that glyphosate translocation increased to the tubers as purple nutsedge plants grew older (Keeley et al. 1985; Pereira et al. 1987). Zandstra and Nishimoto (1977) concluded that the best time to apply glyphosate for purple nutsedge control was when the plant has a maximum number of newly produced rhizomes and tubers. Percent root dry weight reduction of purple nutsedge was influenced by application heights in tank mixtures of trifloxysulfuron at 4 g/ha plus pyrithiobac POST fb MSMA LAYBY, and pyrithiobac plus glyphosate or MSMA at 1,120 g/ha fb MSMA LAYBY.

Yellow Nutsedge. No statistical difference was observed between experiments, thus data were pooled over experiments. A significant interaction was observed between plant size and above- and belowground biomass, therefore data are presented separately.

Shoots. MSMA LAYBY alone with no POST treatment reduced 10- to 15-cm yellow nutsedge shoot dry weights by 44% (Table 2). The addition of trifloxysulfuron at 4 g/ha POST to a MSMA LAYBY reduced shoot dry weight 75% relative to the nontreated control. Control of yellow nutsedge at levels > 80%) has been observed in previous studies with trifloxysulfuron POST in cotton (Burke and Wilcut 2004; Porterfield et al. 2002). Increasing the application rate of trifloxysulfuron to 6 g/ha POST fb MSMA LAYBY decreased percent shoot dry weight growth by 12% compared to trifloxysulfuron at 4 g/ha. This percent shoot dry weight reduction was equivalent to glyphosate POST fb MSMA LAYBY, which resulted in 87% reduction of yellow nutsedge

Table 2. Percent shoot and root/tuber dry weight reduction of 10- to 15-cm and 20- to 30-cm yellow nutsedge resulting from the application of cotton postemergence herbicides (60 DAT).[a] All treatments received a LAYBY application of MSMA at 2,240 g ai/ha 30 DAT.

Postemergence herbicide		10 to 15 cm Shoot dry weight	10 to 15 cm Root/tuber dry weight	20 to 30 cm Shoot dry weight	20 to 30 cm Root/tuber dry weight
	g ai or g ae/ha[b]	% reduction			
No POST	—	44	37	24*[c]	47
Trifloxysulfuron	4	75	73	67*	71
Trifloxysulfuron	5	87	85	69*	73*
Glyphosate	1,120	87	85	64*	77
Glufosinate	400	79	78	52*	69*
MSMA	1,120	75	55	64*	71
MSMA	2,240	73	54	65*	72*
Pyrithiobac	36	45	−2	65*	63*
Trifloxysulfuron + glyphosate	4 + 1,120	78	63	72	83*
Trifloxysulfuron + glufosinate	4 + 400	73	44	66	71
Trifloxysulfuron + MSMA	4 + 1,120	78	65	73	81*
Trifloxysulfuron MSMA	4 + 2,240	86	82	71*	89
Trifloxysulfuron + pyrithiobac	4 + 36	84	80	72*	80
Trifloxysulfuron + glyphosate	6 + 1,120	90	81	64*	83
Trifloxysulfuron + glufosinate	6 + 400	75	55	64	78*
Trifloxysulfuron + MSMA	6 + 1,120	78	58	67	79*
Trifloxysulfuron + MSMA	4 + 2,240	80	69	75	89*
Trifloxysulfuron + pyrithiobac	6 + 36	78	73	71	85
Glyphosate + glufosinate	1,120 + 400	78	53	58*	64
Glyphosate + MSMA	1,120 + 1,120	89	79	76*	90
Glyphosate + MSMA	1,120 + 2,240	80	67	71*	85
Glyphosate + pyrithiobac	1,120 + 36	82	64	59*	84
Glufosinate + MSMA	400 + 1,120	74	63	63*	75
Glufosinate + MSMA	400 + 2,240	81	57	69	79
Glufosinate + pyrithiobac	400 + 36	65	31	60	69*
Pyrithiobac + MSMA	36 + 1,120	81	75	68*	81
Pyrithiobac + MSMA	36 + 2,240	81	85	74	88
LSD (0.05)		7	5	13	15

[a] Percent reduction compared to the nontreated control.

[b] Glyphosate rates are g ae/ha.

[c] * Indicates herbicide treatment significance between height of application.

shoot dry weight. Glufosinate POST fb MSMA LAYBY reduced yellow nutsedge shoot dry weight by 79%. The reduction in yellow nutsedge shoots could allow glufosinate-resistant cotton to achieve a height differential that is essential for effective postdirected herbicides later in the season (Wilcut et al. 1996). MSMA applied POST fb MSMA LAYBY decreased shoot dry weights by at least 73%, and with no difference in rate of application. Pyrithiobac POST fb MSMA LAYBY did not alter percent shoot dry weight reduction significantly. Wilcut (1998) reported only a 6% reduction in shoot dry weight when pyrithiobac was applied to the foliage and soil of yellow nutsedge. In foliar applications, pyrithiobac mostly was translocated to the shoots of yellow nutsedge (Vencill 1998). The addition of trifloxysulfuron POST in combination with MSMA at 2,240 g/ha or pyrithiobac fb MSMA LAYBY reduced percent shoot growth by 11 and 9%, respectively, relative to the herbicides POST alone. The reduced growth could be attributed to the added yellow nutsedge control that trifloxysulfuron offers. However, application of trifloxysulfuron at 6 g/ha in tank mixtures with glufosinate, MSMA, or pyrithiobac POST fb MSMA LAYBY resulted in antagonism, and consequently there was less shoot dry weight reduction. Further antagonism was observed in treatments involving glyphosate plus glufosinate POST fb MSMA LAYBY, decreasing reduction by 9%. Percent shoot dry weight growth was reduced by 20 and 36% when glufosinate or MSMA at either rate was included in a tank mixture with pyrithiobac POST fb MSMA LAYBY. Past research showed that the addition of MSMA to pyrithiobac has significantly improved yellow nutsedge control (Vencill 1998).

A LAYBY treatment of MSMA alone reduced 20- to 30-cm yellow nutsedge shoot dry weight by 24% (Table 2). This reduction was significantly less than the percent shoot dry weight reduction that resulted from the same treatment to 10- to 15-cm yellow nutsedge. POST treatments of trifloxysulfuron at either rate, glyphosate, MSMA at either rate, and pyrithiobac fb MSMA LAYBY reduced shoot dry weights by at least 64%, with no statistical difference occurring for percent reduction between these herbicide programs. Glufosinate POST fb MSMA LAYBY reduced percent shoot dry weight by 52%, which was statistically equivalent to all other single POST herbicide applications except trifloxysulfuron fb MSMA LAYBY. The addition of MSMA at 2,240 g/ha in a tank mixture with glufosinate POST fb MSMA LAYBY produced a synergistic effect, reducing percent shoot dry weight growth by 16%.

More plant growth (represented by lower percent shoot dry weight reductions) between plant heights at application occurred for POST applications of trifloxysulfuron at either rate, glyphosate, glufosinate, and MSMA at either rate, and in several instances that decrease was significant. Several studies have concluded that glyphosate activity on nutsedge species is influenced by size and age of the plants (Keeley et al. 1985; Pereira et al. 1987). Steckel et al (1987) noted that young actively growing plants usually have more permeable cuticles than older plants. In such a situation, penetration of the cuticle by water-soluble herbicides such as glufosinate might increase compared to plants with more developed cuticles. Other decreases in percent reduction by the POST herbicides fb MSMA LAYBY could be attributed to increased tolerance of yellow nutsedge to these herbicides with age or increased tuber production (allowing them to produce more shoots throughout the season). However, yellow nutsedge shoot dry weight reduction was greater by 20% when pyrithiobac POST fb MSMA LAYBY was applied to 20- to 30-cm yellow nutsedge. The reduction in percent growth could be attributed to the increased foliar surface area available to absorb the herbicide, causing greater shoot reduction (Richburg et al. 1993; 1994).

Roots/Tubers. Trifloxysulfuron at 4 g/ha POST fb MSMA LAYBY reduced 10- to 15-cm yellow nutsedge root dry weight by 73% (Table 2). Ackley et al. (1996) suggested that because yellow nutsedge is controlled by soil applications of some ALS-inhibitors, it is likely that root uptake could contribute to yellow nutsedge control by POST applications. Reddy and Bendixen (1989) observed that less than 1% of foliar applied chlorimuron was translocated out of the shoot and into the roots of nutsedge species. Increasing the rate of trifloxysulfuron to 6 g/ha POST fb MSMA LAYBY resulted in a 12 percentage point greater reduction in plant growth. This reduction was equivalent to treatments involving glyphosate POST fb MSMA LAYBY, which decreased root dry weight by 85%. Pereira et al. (1987) suggested treating yellow nutsedge before tubers began to enlarge for optimum control. POST treatments of glufosinate fb MSMA resulted in 78% yellow nutsedge root/tuber reduction. This observation contradicts Steckel et al. (1997), who found that over 88% of the applied ^{14}C-glufosinate remained in the treated leaves of four weed species 72 h after treatment. The high amount of reduction might be due to the effective foliar control observed from the reduction of the shoots, thus decreasing the amount of carbohydrates produced that are used for root and tuber production (Akin and Shaw 2001). MSMA applied in multiple applications as a POST and LAYBY treatment reduced yellow nutsedge root dry weights by at least 54%, regardless of herbicide rate. An increase in root/tuber dry weight relative to the control was observed when pyrithiobac was applied POST fb MSMA LAYBY. Vencill (1998) noted that pyrithiobac translocation to the roots was greatly reduced from foliar applications. Other research has shown increases in root dry weights with foliar treatments of pryithiobac to yellow nutsedge (Richburg et al. 1994; Wilcut 1998). Mixtures of glyphosate, glufosinate, and MSMA at 1,120 g/ha with trifloxysulfuron at either rate POST fb MSMA LAYBY resulted in decreased percent root dry weight reduction compared to trifloxysulfuron POST fb MSMA LAYBY alone. However, decreased growth resulted from the addition of MSMA at 2,240 g/ha or pyrithiobac to trifloxysulfuron at 4 g/ha POST fb MSMA LAYBY. Antagonism was also observed when the POST herbicides were included with glyphosate or glufosinate POST in a tank mixture, fb MSMA LAYBY. An additive interaction was observed when MSMA was included with pyrithiobac POST fb MSMA LAYBY, resulting in at least 75% root/tuber dry weight reduction. However, MSMA rate did influence percent reduction; MSMA at 2,240 g/ha increased root dry weight reduction by 10% compared to MSMA at a lower rate.

All cotton POST herbicides used alone fb MSMA LAYBY reduced 20- to 30-cm yellow nutsedge root/tuber dry weights by at least 63%, with no statistical difference between these herbicide programs. The addition of MSMA at 2,240 g/ha in a tank mixture with trifloxysulfuron POST fb MSMA LAYBY at either rate increased percent root dry weight reduction to 89%. MSMA at either rate was also effective for increasing percent reduction when combined in a tank mixture with pyrithiobac POST fb MSMA LAYBY to at least 81%. Increased foliar intercept and herbicidal activity might have contributed to this increased reduction.

A significant herbicide treatment by application timing interaction occurred for percent root dry weight reduction in herbicide programs involving trifloxysulfuron at 6 g/ha POST fb MSMA LAYBY, causing 12% less reduction. Differential translocation and absorption of trifloxysulfuron could play a role in this decreased reduction. A decrease in reduction was also noted in glufosinate POST fb MSMA LAYBY. Past research has observed that only 11% of absorbed ^{14}C glufosinate reached the roots of several weed species investigated (Mersey et al. 1990; Steckel et al. 1997). However, MSMA at 2,240 g/ha alone or in a tank mixture with trifloxysulfuron at 6 g/ha POST fb MSMA LAYBY, trifloxysulfuron at either rate plus MSMA at 1,120 g/ha fb MSMA LAYBY, pyrithiobac alone or plus glufosinate POST fb MSMA LAYBY, and trifloxysulfuron plus glufosinate fb MSMA LAYBY reduced root/tuber dry weight growth when applied to 20- to 30-cm compared to 10- to 15-cm yellow nutsedge. This significant reduction in percent growth could be contributed to the increased translocation of these herbicides or herbicide combinations to the roots as plants mature, foliar area for herbicide uptake, or the low ($\leq$ 65%) level of percent reduction observed in 10- to 15-cm yellow nutsedge.

These data indicate that trifloxysulfuron, glyphosate, glufosinate, MSMA, and pyrithiobac used POST fb MSMA LAYBY reduce purple and yellow nutsedge root/tuber and shoot dry weights. Nutsedge control is difficult because of the presence of numerous dormant tubers and the ability of the tubers to resprout after disturbance. Effectively reducing root and tuber populations and viability are important aspects for increasing nutsedge control and decreasing densities (Johnson and Mullinix 1997; Molin et al. 1999). Often control of nutsedge is suboptimal because of inconsistent translocation into tubers (Nesser et al. 1997; Troxler et al. 2003). Trifloxysulfuron at either rate POST fb MSMA LAYBY reduced purple and yellow nutsedge root/tuber and shoot dry weights at 10- to 15- and 20- to 30-cm as well as glyphosate POST fb MSMA LAYBY. However, a higher herbicide rate of trifloxysulfuron fb MSMA LAYBY increased 10- to 15-cm yellow nutsedge percent root/tuber and shoot reduction. An advantage for trifloxysulfuron is it can be used in transgenic and nontransgenic cotton. MSMA at either rate fb MSMA LAYBY was effective for reducing purple and yellow nutsedge; however, POST applications can lead to potential yield reductions and maturity delays (Shankle et al. 1996; Wilcut et al. 1995). Although glufosinate is typically not well translocated, (Steckel et al. 1997) it has demonstrated the capability to reduce purple and yellow shoot dry weights significantly. This reduction in shoot matter may induce a height differential between nutsedge and cotton that is essential for postdirecting herbicidal application. According to our data, herbicide programs including pyrithiobac POST fb MSMA LAYBY reduced purple and yellow nutsedge root/tuber and shoot dry weights the least. Although significant reductions occurred, further herbicide or management practices might be necessary for adequate control. Other tank mixes of the cotton POST herbicides fb MSMA LAYBY did not increase the reduction of purple and yellow root/tuber and shoot dry weights. However, further evaluation of these POST herbicides in combinations should be conducted to determine consistent symptoms of antagonism or synergism. Timing of nutsedge application did influence many of the cotton POST programs. However, early application of POST herbicides is recommended to create a height differential and to prevent yield loss due to early season weed interference.

MSMA was effective for increasing percent shoot and root/tuber reduction in yellow nutsedge when included in tank mixtures with glyphosate and trifloxysulfuron. Although MSMA use has decreased since 1996 (Edwards 2006), these data illustrate the value of MSMA for perennial nutsedge control, alone and in combination with glyphosate, glufosinate, pyrithiobac, and trifloxysulfuron. The impending loss of the registration for MSMA (Edwards 2006) could have serious consequences for cotton producers with perennial nutsedge infestations. Furthermore, reliance on ALS-inhibiting herbicides for weed control can rapidly lead to herbicide resistance. Unfortunately, MSMA filled that role as an herbicide with a mode of action different from the ALS-inhibiting herbicides and glyphosate. Consequently, further research is needed to evaluate glyphosate and trifloxysulfuron with other management options in a systems approach for nutsedge management.

Sources of Materials

[1] Purple and yellow nutsedge tubers, Azlin Seed Service, P.O. Box 914, Leland MS 38756.

[2] Miracle-Grow general purpose water soluble plant fertilizer, 24-8-16, Stern's Miracle-Grow Products, Port Washington, NY 11050.

[3] Induce nonionic low foam wetter/spreader adjuvant contains 90% nonionic surfactant (alkylarylpolyoxyalkane ether and isopropanol), free fatty acids, and 10% water, Helena Chemical Company, Suite 500, 6075 Popular Ave., Memphis, TN 38137.

Acknowledgments

The authors wish to thank Walter Thomas, Andy Price, and Scott Clewis for technical support and Dr. Cavell Brownie for review of statistical analyses.

Literature Cited

Ackley, J. A., H. P. Wilson, and T. E. Hines. 1996. Yellow nutsedge (*Cyperus esculentus*) control POST with acetolactate synthase-inhibiting herbicides. Weed Technol. 10:576–580.

Akin, D. S. and D. R. Shaw. 2001. Purple nutsedge (*Cyperus rotundus*) and yellow nutsedge (*Cyperus esculentus*) control in glyphosate-tolerant soybean (*Glycine max*). Weed Technol. 15:564–570.

Askew, S. D. and J. W. Wilcut. 1999. Cost and weed management with herbicide programs in glyphosate-resistant cotton (*Gossypium hirsutum*). Weed Technol. 13:308–313.

Brecke, B. J. and D. O. Stephenson. 2006. Weed control in cotton (*Gossypium hirsutum*) with postermergence applications of trifloxysulfuron-sodium. Weed Technol. 20:377–383.

Brecke, B. J., D. O. Stephenson, and J. B. Unruh. 2005. Control of purple nutsedge (*Cyperus rotundus*) with herbicides and mowing. Weed Technol. 19:809–814.

Burke, I. C., S. C. Troxler, S. D. Askew, J. W. Wilcut, and W. D. Smith. 2005. Weed management systems in glyphosate-resistant cotton. Weed Technol. 19:422–429.

Burke, I. C. and J. W. Wilcut. 2004. Weed management with CGA-362622, fluometuron, and pyrithiobac. Weed Technol. 18:268–276.

Butler, T. J., J. P. Muir, and J. T. Ducar. 2006. Weed control and response to herbicides during Tifton 85 establishment from rhizomes. Agron. J. 98:788–794.

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

Culpepper, A. S. and A. C. York. 1999. Weed management and net returns with transgenic, herbicide-resistant, and nontransgenic cotton (*Gossypium hirsutum*). Weed Technol. 13:411–420.

Doll, J. D. and W. Piedrahita. 1982. Effect of glyphosate on the sprouting of *Cyperus rotundus* L. tubers. Weed Res. 22:123–128.

Dotray, P. A., J. W. Keeling, C. G. Henniger, and J. R. Abernathy. 1996. Palmer amaranth (*Amaranthus palmeri*) and devil's-claw (*Proboscidea louisianca*) control in cotton (*Gossypium hirsutum*) with pyrithiobac. Weed Technol. 10:7–12.

Dowler, C. C. 1998. Weed survey—southern states, broadleaf crops subsection. Proc. South. Weed Sci. Soc. 48:290–305.

Edenfield, M. W., B. J. Brecke, D. L. Colvin, J. A. Dusky, and D. G. Shilling. 2005. Purple nutsedge (*Cyperus rotundus*) control with glyphosate in soybean and cotton. Weed Technol. 19:947–953.

Edwards, D. 2006. Reregistration Eligibility Decision (RED) for MSMA, DSMA, CAMA, and Cacodylic Acid. http://www.epa.gov/oppsrrd1/reregistration/REDs/organic_arsenicals_red.pdf. Accessed: May 3, 2008.

Hamilton, K. C. 1971. Repeated, foliar applications of MSMA on purple nutsedge. Weed Sci. 19:675–677.

Johnson, W. C., III and B. G. Mullinix Jr. 1997. Population dynamics of yellow nutsedge (*Cyperus esculentus*) in cropping systems in the southeastern coastal plain. Weed Sci. 45:166–171.

Jordan, D. L., R. E. Frans, and M. R. McClelland. 1993. Influence of application rate and timing on efficacy of DPX-PE350 applied postemergence. Weed Technol. 7:216–219.

Jordan, D. L., A. C. York, J. L. Griffin, P. A. Clay, P. R. Vidrine, and D. B. Reynolds. 1997. Influence of application variables on efficacy of glyphosate. Weed Technol. 11:354–362.

Keeley, P. E., C. H. Carter, and R. J. Thullen. 1985. Influence of glyphosate on resprouting of parent tubers of *Cyperus esculentus*. Weed Sci. 34:25–29.

Koger, C. H., I. C. Burke, D. K. Miller, J. A. Kendig, K. N. Reddy, and J. W. Wilcut. 2007. MSMA antagonizes glyphosate and glufosinate efficacy on broadleaf and grass weeds. Weed Technol. 21:159–165.

Koger, C. H., A. J. Price, and K. N. Reddy. 2005. Weed control and cotton response to combinations of glyphosate and trifloxysulfuron. Weed Technol. 19:113–121.

Mersey, B. G., J. C. Hall, D. M. Anderson, and C. J. Swanton. 1990. Factors affecting the herbicidal activity of glufosinate ammonium: absorption, translocation, and metabolism in barley and green foxtail. Pestic. Biochem. Physiol. 37:90–98.

Molin, W. T., A. A. Maricic, R. A. Kahn, and C. F. Mancino. 1999. Effect of MON 12037 on the growth and tuber viability of purple nutsedge (*Cyperus rotundus*). Weed Technol. 13:1–5.

Nelson, K. A., K. A. Renner, and D. Penner. 2002. Yellow nutsedge (*Cyperus esculentus*) control and tuber yield with glyphosate and glufosinate. Weed Technol. 16:360–365.

Nesser, C., R. Aguero, and C. J. Swanton. 1997. Survival and dormancy of purple nutsedge (*Cyperus rotundus*) tubers. Weed Sci. 45:784–790.

Pereira, W., G. Crabtree, and R. D. William. 1987. Herbicide action on purple and yellow nutsedge (*Cyperus rotundus* and *C. esculentus*). Weed Technol. 1:92–97.

Porterfield, D., J. W. Wilcut, and S. D. Askew. 2002. Weed management with CGA-362622, fluometuron, and prometryn in cotton. Weed Sci. 50:642–647.

Rao, A. S. and K. N. Reddy. 1999. Purple nutsedge (*Cyperus rotundus*) and sicklepod (*Senna obtusifolia*) response to glyphosate mixtures with ALS-inhibiting herbicides. Weed Technol. 13:361–366.

Reddy, K. N. and L. E. Bendixen. 1989. Toxicity, absorption, and translocation of soil-applied chlorimuron in yellow and purple nutsedge (*Cyperus esculentus* and *C. rotundus*). Weed Sci. 37:147–151.

Richardson, R. J., H. P. Wilson, G. R. Armel, and T. E. Hines. 2004. Mixtures of glyphosate with CGA 362622 for weed control in glyphosate-resistant cotton (*Gossypium hirsutum*). Weed Technol. 18:16–22.

Richburg, J. S., III, J. W. Wilcut, and G. R. Wehtje. 1993. Toxicity of imazethapyr to purple nutsedge (*Cyperus rotundus*) and yellow nutsedge (*C. esculentus*). Weed Technol. 7:900–905.

Richburg, J. S., III, J. W. Wilcut, and G. R. Wehtje. 1994. Toxicity of AC 263,222 to purple nutsedge (*Cyperus rotundus*) and yellow nutsedge (*C. esculentus*). Weed Sci. 42:398–402.

Shankle, M. W., R. M. Hayes, V. H. Reich, and T. C. Mueller. 1996. MSMA and pyrithiobac effects on cotton (*Gossypium hirsutum*) development, yield, and quality. Weed Sci. 44:137–142.

Singh, S. and M. Singh. 2004. Effect of growth stage on trifloxysulfuron and glyphosate efficacy in twelve weed species of citrus groves. Weed Technol. 14:1031–1036.

Steckel, G. J., S. E. Hart, and L. M. Wax. 1997. Absorption and translocation of glufosinate in four weed species. Weed Sci. 45:378–381.

Stoller, E. W. and R. D. Sweet. 1987. Biology and life cycle of purple and yellow nutsedges (*Cyperus rotundus* and *C. esculentus*). Weed Technol. 1:66–73.

Tharp, B. E. and J. J. Kells. 1999. Influence of herbicide application rate, timing, and interrow cultivation on weed control and corn (*Zea Mays*) yield in glufosinate-resitant and glyphosate-resistant corn. Weed Technol. 13:807–813.

Troxler, S. C., I. C. Burke, J. W. Wilcut, and W. D. Smith. 2003. Absorption, translocation, and metabolism of foliar applied CGA-362622 in purple and yellow nutsedge (Cyperus rotundus and C. esculentus). Weed Sci. 51:13–18.

Vencill, W. K. 1998. Uptake, translocation, and metabolism of pyrithiobac-sodium in yellow nutsedge. Proc. South. Weed Sci. Soc. 53:208.

Vencill, W. K., J. S. Richburg, III, J. W. Wilcut, and L. R. Hawf. 1995. Effect of MON-12037 on purple (*Cyperus rotundus*) and yellow (*Cyperus esculentus*) nutsedge. Weed Technol. 9:148–152.

Webster, E. P., D. R. Shaw, T. A. Baughman, C. E. Snipes, and C. T. Bryson. 2000. Influence of cultivation timing on pyrithiobac performance in cotton (*Gossypium hirsutum*). Weed Technol. 14:116–121.

Wilcut, J. W. 1998. Influence of pyrithiobac sodium on purple (*Cyperus rotundus*) and yellow nutsedge (*C. esculentus*). Weed Sci. 46:111–115.

Wilcut, J. W., H. D. Coble, A. C. York, and D. W. Monks. 1996. The niche for herbicide-resistant crops in U.S. agriculture. Pages 213–230 *in* S. O. Duke, ed. Herbicide-Resistant Crops: Environmental, Economic, Regulatory, and Technical Aspects. Boca Raton, FL: CRC.

Wilcut, J. W., A. C. York, and D. L. Jordan. 1995. Weed management programs for oil seed crops. Pages 343–400 *in* A. E. Smith, ed. Handbook of Weed Management Programs. New York: Marcel Dekker.

Zandstra, B. H. and R. K. Nishimoto. 1977. Movement and activity of glyphosate in purple nutsedge. Weed Sci. 25:268–272.

Received December 27, 2007, and approved August 22, 2008.