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Purple Nutsedge (*Cyperus rotundus*) and False-Green Kyllinga (*Kyllinga gracillima*) Control in Bermudagrass Turf

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Experiments were conducted during 2007 and 2008 to evaluate various herbicide treatment regimes for POST purple nutsedge and false-green kyllinga control. Evaluated herbicides included halosulfuron, sulfentrazone, sulfosulfuron, and trifloxysulfuron. Evaluated treatments did not cause objectionable bermudagrass injury at any time. Results were variable across years, likely due to reduced rainfall in 2007 causing reduced purple nutsedge and false-green kyllinga growth. In 2007, averaged across herbicide rate and number of applications, sulfosulfuron provided greater purple nutsedge control than trifloxysulfuron. Sulfosulfuron and trifloxysulfuron provided similar levels of control in 2008, although both were less effective than in 2007. In 2007, sulfosulfuron and trifloxysulfuron provided excellent ($> 90\%$) false-green kyllinga control, and trifloxysulfuron provided greater control (80%) compared to sulfosulfuron (61%) in 2008. Sulfentrazone provided < 30 and 60% purple nutsedge and false-green kyllinga control, respectively. A sequential application applied 6 wk after initial treatment provided the highest level of purple nutsedge and false-green kyllinga control with evaluated herbicides. Tank-mix partners to enhance purple nutsedge control with sulfentrazone provided inconsistent results. Sulfosulfuron and trifloxysulfuron offer acceptable POST perennial sedge control in tolerant warm-season turfgrasses.
Nomenclature: Halosulfuron; sulfentrazone; sulfosulfuron; trifloxysulfuron; false-green kyllinga, *Kyllinga gracillima* L.; purple nutsedge, *Cyperus rotundus* L.; bermudagrass, *Cynodon* spp.
Key words: Herbicide efficacy, sequential applications, sequential application timing, tank-mix partner.

Durante 2007 y 2008 se realizaron experimentos para evaluar varios regímenes de tratamientos de herbicida para el control pos-emergente de *Cyperus rotundus* y *Kyllinga gracillima*. Los herbicidas evaluados incluyeron halosulfuron, sulfentrazone, sulfosulfuron y trifloxysulfuron. Los tratamientos evaluados no causaron daño objetable al *Cynodon* spp. en ningún momento. Los resultados fueron variables entre años, probablemente debido a la escasez de lluvias en 2007 que provocó una reducción en el crecimiento de *C. rotundus* y *K. gracillima*. En 2007, sacando un promedio entre todas las dosis de herbicida y número de aplicaciones, el sulfosulfuron proporcionó un mayor control de *C. rotundus* que el trifloxysulfuron. Sulfosulfuron y trifloxysulfuron proporcionaron niveles similares de control en 2008, aunque ambos fueron menos efectivos que en 2007. En 2007, sulfosulfuron y trifloxysulfuron proporcionaron un excelente control ($> 90\%$) de *K. gracillima,* mientras que trifloxysulfuron proporcionó mayor control (80%) comparado con sulfosulfuron (61%) en 2008. Sulfentrazone proporcionó un control de *C. rotundus* y *K. gracillima* de < 30 y 60%, respectivamente. Una aplicación secuencial realizada 6 semanas después del tratamiento inicial proporcionó el nivel más alto de control de *C. rotundus* y *K. gracillima* con los herbicidas evaluados. Mezclas con otros herbicidas para mejorar el control de *C. rotundus* con sulfentrazone, proporcionaron resultados inconsistentes. Sulfosulfuron y trifloxysulfuron ofrecen control pos-emergente aceptable de especies perenes de la familia Cyperaceae en céspedes tolerantes a estaciones calurosas.

Purple nutsedge and false-green kyllinga are common perennial sedge species (Cyperaceae) in turfgrass systems. Purple nutsedge and most kyllinga spp. are C_4 plants (Bryson and Carter 2008; Lin et al. 1993) which possess specialized leaf anatomy allowing increased growth and efficiency under high light and temperature regimes (Hattersley 1983; Lin et al. 1993; Teeri and Stowe 1976). Purple nutsedge and false-green kyllinga thrive in moist soil conditions (Bendixen and Nandihalli 1987; McElroy et al. 2005a). Summerlin et al. (2000) concluded that routine mowing of golf course fairways at 1.3 cm suppresses purple nutsedge growth, although additional control methods were required to provide acceptable levels of control. In contrast, false-green kyllinga is able to withstand frequent mowing at heights as low as 1.3 cm (Bryson et al. 1997; Summerlin et al. 2000). Observations of green kyllinga (*Kyllinga brevifolia* Rottb.) and false-green kyllinga maintained under golf course putting green conditions indicate these species may tolerate frequent mowing (F. H. Yelverton, personal observation).

Native to India, purple nutsedge is a rapidly spreading perennial with three-ranked basal leaves usually shorter than the flowering stem (Chase and Appleby 1979; McCarty et al. 2008). Although not as widely distributed as other *Cyperus* species, purple nutsedge was described as the world's worst weed because it is a serious competitor with more crops in more countries than any other weed (Holm et al. 1977). The geographic distribution of purple nutsedge is restricted by lower temperature and soil moisture levels (Bendixen and Nandihalli 1987), although its distribution appears to have increased over the last 25 yr. According to the Weed Identification Guide (Elmore 1985), purple nutsedge was distributed mostly in the southeastern United States north to Virginia, south to Florida, and west to Texas. It has since been reported in California, Arizona, West Virginia, Kentucky, and

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northward into Pennsylvania and New Jersey (Bryson and Carter 2008; Elmore 1990; Murphy et al. 1992).

Purple nutsedge spreads by basal bulbs, viable seed, and tuber chains that are connected by slender rhizomes (Murphy et al. 1992); Stoller and Sweet (1987) concluded seed are not important in purple nutsedge propagation. Purple nutsedge may be differentiated from yellow nutsedge by inflorescence color, absence of tuber chains in yellow nutsedge, and leaf tip shape (Bryson and DeFelice 2009). Although yellow nutsedge has been cultivated for its edible tubers in southern Europe and Africa, purple nutsedge tubers are not used for food and have an undesirable bitter taste (Bryson and DeFelice 2009; Wills 1987).

False-green kyllinga is an aromatic rhizomatous mat-forming perennial native to Asia (Bryson et al. 1997). The reported geographic distribution of false-green kyllinga varies, but it is unclear if this is due to spread over time or misidentification. Bryson et al. (1997) reported the species had spread to include nine additional states in the previous two decades. McCarty et al. (2008) reported false-green kyllinga distribution in the United States from Pennsylvania south to Florida, west to Texas and also in California; however, Bryson et al. (1997) and United States Department of Agriculture (USDA) (2010a) did not report false-green kyllinga in Florida, Louisiana, Texas, or California. Bryson et al. (1997) and USDA (2010a) also reported false-green kyllinga as far north as Connecticut.

False-green kyllinga is similar vegetatively to green kyllinga and can only be differentiated by seed morphology or flower timing (Bryson et al. 1997). Scale keels of green and false-green kyllinga seed are toothed (denticulate) and smooth, respectively (Bryson et al. 1997). False-green kyllinga fruit development is photoperiod dependent, occurring in late summer until frost, whereas green kyllinga fruits during most summer months (Bryson et al. 1997; McCarty et al. 2008). False-green kyllinga may be propagated by seed or rhizomes (McCarty et al. 2008) and is spread as a contaminant of turfgrass sod and sprigs (Bryson et al. 1997).

Changes in herbicide programs have contributed to an increase in *Kyllinga* and *Cyperus* incidence in turfgrass environments (Yelverton 1996). Traditionally, POST monosodium salt of methylarsonic acid (MSMA) applications were applied to control summer annual grasses, including crabgrass (*Digitaria* spp.) and goosegrass (*Eleusine indica*) while also controlling nutsedge and kyllinga species. Today, turfgrass managers rely less on POST herbicides in favor of PRE herbicides that do not control *Kyllinga* and *Cyperus* species from perennial structures.

Previous research has evaluated various herbicides and combinations for purple nutsedge and false-green kyllinga control. Selective herbicide options are available in most turfgrasses, although each species is difficult to control long term as they possess vegetative structures capable of overwintering in select climates. Blum et al. (2000) reported minimal purple nutsedge control ($\leq 25\%$) with single sulfentrazone applications (0.42 kg ha^{-1}) in established turfgrass; however, Grichar et al. (2003) reported greater than 75% control in field crops. Sulfentrazone provides $> 75\%$ false-green kyllinga control, whereas repeat trifloxysulfuron applications provide $> 85\%$ false-green kyllinga control in turfgrass systems (McElroy et al. 2005b). Sulfosulfuron (Baumann et al. 2004; Brecke et al. 2007; Eizenberg et al. 2003; Harrell et al. 2009; Hubbard et al. 2007) and trifloxysulfuron (Brecke et al. 2004; Burke et al. 2008; Hubbard et al. 2007) have been reported to provide acceptable purple nutsedge control. However, research comparing sulfentrazone, sulfosulfuron, and trifloxysulfuron for perennial sedge control in turfgrass environments is not currently available. Further, little research has been published that describes the optimum sequential application timing for sedge control with sulfonylurea herbicides. The trifloxysulfuron label suggests repeat applications 4 to 6 wk after initial application for tough-to-control perennial weeds including *Kyllinga* and *Cyperus* spp. (Anonymous 2010a), whereas other sulfonylurea herbicide labels (halosulfuron) suggest repeat applications 6 to 10 wk after initial application (Anonymous 2010b). The sulfentrazone product label recommends applying a sequential "when evidence of actively growing purple nutsedge is visible" or "35 DAIT" (Anonymous 2010c). Hence trials were designed to compare application rates and sequential application timings of trifloxysulfuron and sulfentrazone for false-green kyllinga and purple nutsedge control.

The objectives of this research were to evaluate (1) single versus sequential sulfentrazone, sulfosulfuron, and trifloxysulfuron applications for purple nutsedge and false-green kyllinga control, (2) timing of sequential sulfentrazone or trifloxysulfuron application for purple nutsedge and false-green kyllinga control, and (3) sulfentrazone tank-mix partners to enhance purple nutsedge control.

Materials and Methods

Herbicide, Application Rate and Sequential Application. Experiments were initiated to investigate the effect of herbicide, application rate, and one versus two applications for purple nutsedge and false-green kyllinga control. Purple nutsedge control experiments were conducted at Plymouth Country Club in Plymouth, NC in 2007 and New Bern Country Club in Trent Woods, NC in 2008. Soil type at the Plymouth Country Club was a Wahee fine sandy loam (fine, mixed, semiactive thermic Aeric Endoaquults) with 1.3% humic matter (HM) and pH 5.5 (USDA 2010b). Soil type at the New Bern Country Club was Tarboro sand (mixed, thermic Typic Udipsamments) with 1.6% HM and pH 5.9 (USDA 2010b). False-green kyllinga control experiments were conducted at Hidden Valley Golf Club near Fuquay-Varina, NC in 2007 and The Emerald Golf Club in New Bern, NC in 2008. Soil type at Hidden Valley Golf Club was a Wagram loamy sand (loamy, kaolinitic, thermic Arenic Kandiudults) with 1.7% HM and pH 4.9 (USDA 2010b). Soil type at The Emerald Golf Club was a Tarboro sand with 1.4% HM and pH 5.9 (USDA 2010b). HM was determined by the NaOH/DTPA–alcohol extraction method at the North Carolina State Department of Agriculture Plant and Soil Laboratory in Raleigh, NC (Mehlich 1984).

Experiments were initiated in common bermudagrass (*Cynodon dactylon* L. Pers.) naturally infested with purple nutsedge or false-green kyllinga. The purple nutsedge density ranged from 10 to 35%, whereas false-green kyllinga density ranged from 30 to 90% at trial initiation. The bermudagrass turf was irrigated and fertilized per recommended practice. Purple nutsedge control experiments were conducted in a golf course fairway mown at 1.9 cm three to four times per week. False-green kyllinga experiments were conducted in a golf course rough mown at 3.8 cm two to three times per week. Experimental design was a randomized complete block with a factorial arrangement of treatments and four replications. Plot size ranged from 1.9 to 2.2 m^2.

Three herbicides (sulfentrazone [Dismiss®, FMC Professional Solutions, Philadelphia, PA], sulfosulfuron [Certainty®, Monsanto Company, St. Louis, MO], or trifloxysulfuron [Trifloxysulfuron, Monument®, Syngenta Crop Protection Inc., Greensboro, NC]), three application rates (low, medium, or high), and one versus two applications were evaluated. A nontreated was included in each experiment. Single application treatments were applied at experiment initiation only, whereas plots receiving two herbicide applications were treated at experiment initiation and 6 wk after initial treatment (WAIT). Herbicides and rates evaluated were sulfentrazone at 0.14, 0.28, or 0.42 kg ai ha^{-1}, sulfosulfuron at 0.033, 0.049, or 0.066 kg ha^{-1}, or trifloxysulfuron at 0.015, 0.022, or 0.029 kg ha^{-1}. The rate structure was selected to reflect low, medium, and high rates for each herbicide. A nonionic surfactant (X-77 Spreader®, Loveland Industries Inc., Greeley, CO) was included with trifloxysulfuron and sulfosulfuron (0.25% vol vol^{-1}). Herbicide applications were made with a handheld CO_2-propelled research plot sprayer calibrated to deliver 304 L/ha with four 8002XR flat fan nozzles (TeeJet® Extended Range flat-fan spray nozzles, Spraying Systems Co., Glendale Heights, IL) on a 25-cm spacing at 193 kPa. Experiments were initiated mid- to late June.

Data collected included purple nutsedge or false-green kyllinga shoot density and visual estimates of control. Control was visually estimated at 4, 8, and 12 WAIT utilizing a 0 (no visible injury) to 100% (complete plant death) scale. Shoot density was recorded 12 WAIT as the number of emerged shoots in two randomly selected areas of 0.07 m^2 for purple nutsedge and 0.01 m^2 for false-green kyllinga in each plot. Percent shoot-number reduction, relative to the nontreated, was calculated by

$$((\text{nontreated} - \text{treated})/\text{nontreated}) \times 100. \qquad [1]$$

Purple nutsedge tubers and false-green kyllinga rhizomes were also collected 12 WAIT to determine viability. Purple nutsedge tubers were harvested by removing a minimum of three soil cores from each plot with the use of a standard golf cup cutter (10.8 cm diameter by 20.3 cm deep) and tubers were removed from the soil. Stoller and Sweet (1987) reported most purple nutsedge tubers were located within 15 cm of the soil surface. False-green kyllinga rhizomes were harvested similarly, except cores were 7.6 cm deep. Five purple nutsedge tubers or false-green kyllinga rhizomes were immediately planted 0.6 to 1.3 cm deep in growing medium (Metro-mix 350®, Sun-Gro Horticultural Distribution Inc., Bellevue, WA). Flats were placed in a greenhouse with day/night temperatures of 31/20 C and were irrigated from overhead three times per day. Lighting was supplemented (350 μmol/m^2/s) with metal halide lamps (1,000 watts) to simulate 16-h day length. Tubers and rhizomes were grown for 1 mo and were inspected for emergence. Emerged vegetative structures were deemed viable, and nonemerged were considered to be nonviable and percent tuber or rhizome viability was calculated.

Significant main effects and interactions were detected among species; therefore, purple nutsedge and false-green kyllinga data were analyzed separately. Data were arcsine square root transformed to increase homogeneity of variance (Zar 1999), subjected to ANOVA ($P = 0.05$), and means were separated according to Fisher's Protected LSD with the use of SAS (Statistical Analysis Software®, version 9.2, SAS Institute Inc., Cary, NC).

Nontransformed means are presented for clarity with statistical interpretation based on transformed data.

Herbicide, Sequential Application Timing, and Herbicide Rate. Experiments were initiated to determine the effect of herbicides, sequential application timings, and herbicide rates for purple nutsedge and false-green kyllinga control. Experiment location, design, application, and data collection were identical to those described above.

Two herbicides (sulfentrazone or trifloxysulfuron), three sequential application timings (4, 6, or 8 WAIT), and three herbicide application rates (low, medium, or high) were evaluated. Herbicides and rates were sulfentrazone at 0.14, 0.21, or 0.28 kg ha^{-1} or trifloxysulfuron at 0.015, 0.022, or 0.029 kg ha^{-1}. A nonionic surfactant was included with trifloxysulfuron (0.25% vol vol^{-1}). Single applications and a nontreated were included in each experiment for comparison.

Herbicide Tank-Mix Partners with Sulfentrazone for Purple Nutsedge Control. Past research indicates purple nutsedge control with sulfentrazone may be inconsistent. Therefore, experiments were initiated to investigate the effect of herbicide tank-mix partners with sulfentrazone and application rates for purple nutsedge control. Experiment location, design, application, and data collection were identical to those described above.

Herbicides included sulfentrazone alone or tank mixed with halosulfuron (Sedgehammer®, Gowan Company, Yuma, AZ), sulfosulfuron, or trifloxysulfuron. Two rates of each herbicide were evaluated: 0.28 or 0.42 kg ha^{-1} sulfentrazone, 0.035 or 0.07 kg ha^{-1} halosulfuron, 0.033 or 0.066 kg ha^{-1} sulfosulfuron, or 0.015 or 0.029 kg ha^{-1} trifloxysulfuron. A nonionic surfactant (0.25% vol vol^{-1}) was included with all treatments except sulfentrazone alone. Nontreated plots were included in each experiment.

Results and Discussion

In evaluating main effects and interactions, significant ($P \leq 0.05$) year effects were observed for control, shoot-number reduction, and tuber viability; therefore, data were not pooled over years. Further, interactions were not significant; therefore, main effects are reported. Bermudagrass injury was never objectionable (< 20%) throughout experiments (data not shown). The authors feel data collected 12 WAIT is most reflective of results; therefore, data collected 4 and 8 WAIT will not be discussed.

Table 1. Influence of herbicide on purple nutsedge or false-green kyllinga control, shoot-number reduction, and tuber or rhizome viability 12 WAIT.[a]

	CYPRO						KYLGR					
	Control[c]		Shoot-number reduction[d]		Tuber viability[e]		Control[c]		Shoot-number reduction[d]		Rhizome viability[e]	
Herbicide[b]	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008
	%											
Sulfentrazone	21	29	19	32	88	89	44	51	58	53	40	21
Sulfosulfuron	92	50	98	65	33	51	91	61	87	79	13	0
Trifloxysulfuron	77	58	88	69	69	71	100	80	98	83	13	0
Nontreated	0	0	–	–	100	100	0	0	–	–	100	100
$LSD_{0.05}$	5	5	23	16	14	8	6	6	9	15	14	7

[a] WAIT, weeks after initial treatment; CYPRO, purple nutsedge; KYLGR, false-green kyllinga; LSD, least-significant difference. Data pooled over application rates and number of applications (one or two).

[b] Evaluated herbicide application rates: sulfentrazone (0.14, 0.28, or 0.42 kg ai ha^{-1}); sulfosulfuron (0.033, 0.049, or 0.066 kg ha^{-1}); trifloxysulfuron (0.015, 0.022, or 0.029 kg ha^{-1}).

[c] Percent control based on visual estimates (0 = no visual symptoms; 100 = complete plant death).

[d] Percent shoot-number reduction relative to nontreated.

[e] Percent viability calculated from shoot emergence from harvested CYPRO tubers or KYLGR rhizomes.

Herbicide, Application Rate, and Sequential Application. Reduced rainfall throughout 2007 likely reduced purple nutsedge and false-green kyllinga growth and resulted in overall improved control in 2007 compared to 2008. Cumulative rainfall during trial periods in 2007 was 18.0 cm (Plymouth, NC, purple nutsedge) and 15.8 cm (Fuquay Varina, NC, false-green kyllinga); 29.1 cm was recorded during 2008 (New Bern, NC, false-green kyllinga and purple nutsedge).

At 12 WAIT in 2007, sulfosulfuron provided greater purple nutsedge control (92%) than trifloxysulfuron (77%) when averaged across herbicide rate and number of applications (Table 1). In 2008, purple nutsedge control with sulfosulfuron and trifloxysulfuron was only 50 and 58%, respectively, less than observed in 2007. This was likely due to increased rainfall in 2008 that was more conducive to purple nutsedge growth. Purple nutsedge shoot-number reduction data followed trends similar to visual estimates of control. Purple nutsedge is a difficult-to-control perennial species, and previous research shows that repeat applications may be required for acceptable control in turfgrass environments (Brecke et al. 2007; Hubbard et al. 2007). Specifically, one or two applications of sulfosulfuron (Baumann et al. 2004; Brecke et al. 2004, 2007; Harrell et al. 2009; Hubbard et al. 2007; Marvin et al. 2009) or trifloxysulfuron (Brecke et al. 2004; Henry and Sladek 2008; Hubbard et al. 2007) provide acceptable purple nutsedge control. Purple nutsedge control with sulfosulfuron and trifloxysulfuron in these studies may have been lower due to inclusion of low application rates and single applications.

Regardless of year, sulfentrazone provided unacceptable (< 30%) POST purple nutsedge control or shoot-number reduction 12 WAIT (Table 1). Previous research has shown that sulfentrazone provides inconsistent purple nutsedge control. Single sulfentrazone applications (0.42 kg ha^{-1}) provided unacceptable (< 50%) purple nutsedge control (Blum et al. 2000; Kopec and Gilbert 2001; Marvin et al. 2009), however, repeat applications have been reported to provide acceptable control. Marvin et al. (2009) reported a sequential sulfentrazone application (0.28 kg ha^{-1} each) applied 28, 35, or 42 DAIT provided 70, 85, or 90% purple nutsedge control, respectively; however, evaluations were conducted in mid-August and may not have accounted for regrowth after sequential application. Similarly, Kopec and Gilbert (2001) reported 77% control with sulfentrazone (0.42 followed by [fb] 0.14 kg ha^{-1}) five WAIT, whereas Blum et al. (2000) reported < 50% control with 0.42 fb 0.42 kg ha^{-1}. Brecke et al. (2005) reported 86% control with 0.42 kg ha^{-1} applied PRE fb 0.14 kg ha^{-1} applied early POST, indicating that purple nutsedge may be more susceptible during emergence or early POST; however, this research was completed in a disked field, which may have influenced the results. Although organic-matter content in Brecke et al. (2005) was similar to our research sites (approximately 2%), because the area was disked prior to initiation, the area likely did not have an organic-matter layer near the soil surface, possibly allowing sulfentrazone to distribute in the root zone, increasing root absorption. The thatch layer, comprised of organic matter, near the soil surface of an established turfgrass may readily adsorb sulfentrazone and reduce root absorption (Ohmes and Mueller 2007).

In our studies, no surfactant or adjuvant was included with sulfentrazone per label recommendations (Anonymous 2010b). Inclusion of a surfactant in previous research may explain greater purple nutsedge control, as Dayan et al. (1996) reported enhanced foliar absorption and yellow nutsedge control when a nonionic surfactant was included compared to sulfentrazone alone. Dayan et al. (1996) also concluded that a nonionic surfactant enhanced soybean (*Glycine max* L.) injury compared to sulfentrazone alone, likely due to increased uptake.

Purple nutsedge tubers harvested from nontreated plots were 100% viable (Table 1). Sulfosulfuron reduced purple nutsedge tuber viability the greatest (67 and 49%, respectively, in 2007 and 2008). Trifloxysulfuron reduced tuber viability (31 and 29%, respectively, in 2007 and 2008) compared to the nontreated, whereas tubers harvested from sulfentrazone-treated plots were ≥ 88% viable. Long-term purple nutsedge control requires effective reduction in tuber population and

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Table 2. Influence of herbicide application rate on purple nutsedge or false-green kyllinga control and shoot-number reduction 12 WAIT.[a]

	CYPRO				KYLGR			
	Control[c]		Shoot-number reduction[d]		Control[c]		Shoot-number reduction[d]	
Herbicide rate[b]	2007	2008	2007	2008	2007	2008	2007	2008
	%							
Low	55	37	64	43	66	48	69	57
Medium	63	49	62	60	82	67	87	76
High	71	52	79	63	87	76	88	81
$LSD_{0.05}$	5	5	NS	16	6	6	9	15

[a] WAIT, weeks after initial treatment; CYPRO, purple nutsedge; KYLGR, false-green kyllinga; LSD, least-significant difference; NS, nonsignificant. Data pooled over herbicides and number of applications (one or two).

[b] Herbicides and application rates (low, medium, and high): sulfentrazone (0.14, 0.28, or 0.42 kg ai ha^{-1}); sulfosulfuron (0.033, 0.049, or 0.066 kg ha^{-1}); trifloxysulfuron (0.015, 0.022, or 0.029 kg ha^{-1}).

[c] Percent control based on visual estimates (0 = no visual symptoms; 100 = complete plant death).

[d] Percent shoot-number reduction relative to nontreated.

viability (Johnson and Mullinix 1997; Molin et al. 1999). Some previous research has demonstrated that sulfonylurea herbicides affect purple nutsedge tuber viability. Molin et al. (1999) concluded halosulfuron did not affect purple nutsedge tuber number or weight, although two applications reduced viability in field experiments. Brecke et al. (2005) reported a 55% reduction in purple nutsedge tuber number and 38% reduction in viability with two halosulfuron applications, and Nelson and Renner (2002) reported > 75% yellow nutsedge tuber number and weight reduction in greenhouse experiments with halosulfuron. Purple nutsedge control with herbicides may be suboptimal because of inconsistent or minimal translocation into tubers (Nesser et al. 1997). Previous research has reported minimal (≤ 4%) translocation into roots and tubers from foliar applications of sulfentrazone (Wehtje et al. 1997) or trifloxysulfuron (Troxler et al. 2003), indicating inadequate basipetal translocation may be a limiting factor in long-term purple nutsedge control.

Similar to purple nutsedge, false-green kyllinga control was numerically less in 2008, likely due to increased rainfall after application (Table 1). In 2007, trifloxysulfuron provided complete false-green kyllinga control and sulfosulfuron provided 91% control 12 WAIT. In 2008, trifloxysulfuron and sulfosulfuron provided 80 and 61% control, respectively. Shoot-number reduction followed trends similar to visual estimates of control. These results concur with previous research that reported acceptable false-green kyllinga control with trifloxysulfuron (Breeden and McElroy 2005; McElroy et al. 2005b) or sulfosulfuron (Brosnan and Deputy 2008; Unruh and Brecke 2006).

Sulfentrazone did not provide acceptable false-green kyllinga control or shoot-number reduction (≤ 58%). Similarly, McElroy et al. (2005b) reported 59 and 65% false-green kyllinga control with 0.42 and 0.56 kg ha^{-1} sulfentrazone, respectively, 1 yr after treatment. These data indicate that adequate false-green kyllinga control may not be obtained each year in turfgrass environments and as previously mentioned may be affected by application rate, inclusion of a surfactant, and rainfall, among other factors.

Similar to purple nutsedge, false-green kyllinga perennial structure viability must be reduced in order to achieve long-term control. False-green kyllinga rhizomes harvested from nontreated areas were 100% viable and evaluated herbicides reduced viability (Table 1). Sulfosulfuron and trifloxysulfuron reduced false-green kyllinga rhizome viability by 87 and 100%, respectively, in 2007 and 2008. Sulfentrazone reduced rhizome viability (40 and 21%, respectively, in 2007 and 2008) compared to the nontreated. The reduction in false-green kyllinga rhizome viability with foliar-applied sulfosulfuron or trifloxysulfuron is likely due to significant translocation to this region. Although foliar-applied trifloxysulfuron is distributed mainly in the treated leaf and primary shoot of false-green kyllinga, appreciable trifloxysulfuron translocates to rhizomes and roots (McElroy et al. 2004).

Excluding purple nutsedge in 2007, medium and high herbicide rates provided greater purple nutsedge or false-green kyllinga control and shoot-number reduction compared to low rates (Table 2). Although numerically greater, in most cases the highest evaluated rate did not statistically increase false-green kyllinga or purple nutsedge control or shoot-number reduction compared to the medium rate. In 2007, medium and high rates of evaluated herbicides provided 63 and 71% purple nutsedge control, respectively, whereas control was 14 to 19% less in 2008. False-green kyllinga control was 11 to 15% greater in 2007, with medium and high herbicide rates providing > 80% control. McElroy et al. (2005b) reported similar false-green kyllinga control with 0.42 or 0.56 kg ha^{-1} sulfentrazone providing 77 and 87%, respectively.

Increased herbicide rates may increase weed control, particularly with difficult-to-control species such as perennial sedges. The lowest rate evaluated in our study was lower than recommended for control of sedge species (Anonymous 2010a to c). In most instances, medium herbicide rates provided false-green kyllinga or purple nutsedge control equal to control observed with higher rates, indicating the maximum use rates are not always beneficial. Additionally, seasonal rainfall amounts may affect herbicide efficacy.

Excluding purple nutsedge in 2007, purple nutsedge and false-green kyllinga control and shoot-number reduction were enhanced with two applications compared to a single application (Table 3). In 2008, two applications improved purple nutsedge and false-green kyllinga control by 26 and

Table 3. Influence of sequential herbicide application on purple nutsedge or false-green kyllinga control and shoot-number reduction 12 WAIT.[a]

	CYPRO				KYLGR			
	Control[b]		Shoot-count reduction[c]		Control[b]		Shoot-count reduction[c]	
No. applications	2007	2008	2007	2008	2007	2008	2007	2008
	%							
1	61	33	64	41	68	53	69	57
2	65	59	72	70	89	75	94	86
$LSD_{0.05}$	NS	4	NS	13	5	6	7	13

[a] WAIT, weeks after initial treatment; CYPRO, purple nutsedge; KYLGR, false-green kyllinga; LSD, least-significant difference; NS, nonsignificant. Data pooled over herbicides and application rates. Evaluated herbicides and application rates: sulfentrazone (0.14, 0.28, or 0.42 kg ai ha^{-1}); sulfosulfuron (0.033, 0.049, or 0.066 kg ha^{-1}); trifloxysulfuron (0.015, 0.022, or 0.029 kg ha^{-1}).

[b] Percent control based on visual estimates (0 = no visual symptoms; 100 = complete plant death).

[c] Percent shoot-number reduction relative to nontreated.

22%, respectively, compared to a single application. Similarly, two applications enhanced purple nutsedge and false-green kyllinga shoot-number reduction by 29% in 2008 compared to a single application. Several researchers have concluded sequential applications are required for acceptable perennial Cyperaceae control. For example, Hubbard et al. (2007) reported 45% purple nutsedge control with a single trifloxysulfuron application; whereas control was enhanced to 90% when a sequential treatment was applied. Similarly, Brecke et al. (2007) reported two sulfosulfuron applications were required for acceptable purple nutsedge control. The enhanced control at 12 WAIT is most likely due to the sequential application providing control of sedge regrowth after initial application.

Herbicide, Sequential Application Timing, and Herbicide Rate. Regardless of year, trifloxysulfuron provided greater purple nutsedge and false-green kyllinga control and shoot-number reduction compared to sulfentrazone (Table 4). Trifloxysulfuron provided 70 and 69% purple nutsedge control in 2007 and 2008, respectively, while providing 100 and 83% false-green kyllinga control in 2007 and 2008, respectively. Regardless of year, sulfentrazone provided ≤ 43% purple nutsedge or false-green kyllinga control. Similar trends were observed with purple nutsedge and false-green kyllinga shoot-number reduction. Trifloxysulfuron reduced purple nutsedge shoot number by 73 and 90%, respectively, in 2007 and 2008 and provided ≥ 92% false-green kyllinga shoot-number reduction in both years.

The ability of plants to emerge from numerous tubers makes control of tuberous perennial sedge species difficult. Trifloxysulfuron reduced purple nutsedge tuber and false-green kyllinga rhizome viability to a greater extent than sulfentrazone (Table 4). In 2007 and 2008, trifloxysulfuron reduced purple nutsedge tuber viability by 23 and 58%, respectively. Although significantly reduced compared to the nontreated, sulfentrazone treatments only reduced purple nutsedge tuber viability ≤ 12%. As stated above, previous research reported minimal trifloxysulfuron translocation into purple nutsedge roots and tubers, indicating this may be a limiting factor in effective tuber viability reduction (Troxler et al. 2003). Similarly, Nesser et al. (1997) concluded herbicidal purple nutsedge control is often suboptimal because of inconsistent herbicide translocation into tubers. Wehtje et al. (1997) reported minimal sulfentrazone translocation into purple nutsedge roots and tubers, indicating sulfentrazone may not reduce purple nutsedge tuber viability.

Herbicides translocate shorter distances to rhizomes compared to tubers, which may have attributed to greater

Table 4. Influence of herbicide on purple nutsedge or false-green kyllinga control, shoot-number reduction, and tuber or rhizome viability 12 WAIT.[a]

	CYPRO						KLYGR					
	Control[c]		Shoot-number reduction[d]		Tuber viability[e]		Control[c]		Shoot-number reduction[d]		Rhizome viability[e]	
Herbicide[b]	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008
	%											
Sulfentrazone	32	20	51	61	90	88	43	37	37	58	60	30
Trifloxysulfuron	70	69	73	90	77	42	100	83	100	92	8	5
Nontreated	0	0	–	–	100	100	0	0	–	–	100	100
$LDS_{0.05}$	4	3	16	7	8	6	3	3	10	5	10	11

[a] WAIT, weeks after initial treatment; CYPRO, purple nutsedge; KYLGR, false-green kyllinga; LSD, least-significant difference. Data pooled over sequential application timing (4, 6, or 8 WAIT) and herbicide application rates.

[b] Evaluated herbicide application rates (sulfentrazone: 0.14, 0.21, or 0.28 kg ai ha^{-1}; trifloxysulfuron: 0.015, 0.022, or 0.029 kg ha^{-1}).

[c] Percent control based on visual estimates (0 = no visual symptoms; 100 = complete plant death).

[d] Percent shoot-number reduction relative to nontreated.

[e] Percent viability based on shoot emergence from harvested tubers or rhizomes that were planted in greenhouse.

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Table 5. Influence of sequential application timing on purple nutsedge or false-green kyllinga control and shoot-number reduction 12 WAIT.[a]

	CYPRO				KLYGR			
	Control[b]		Shoot-number reduction[c]		Control[b]		Shoot-number reduction[c]	
Sequential timing	2007	2008	2007	2008	2007	2008	2007	2008
	%							
No. sequential	38	35	52	65	62	54	60	60
4 WAIT	51	54	51	78	69	64	71	77
6 WAIT	63	62	75	86	84	62	78	83
8 WAIT	54	29	71	74	70	60	66	80
$LSD_{0.05}$	6	4	22	10	4	5	15	7

[a] WAIT, weeks after initial treatment; CYPRO, purple nutsedge; KYLGR, false-green kyllinga; LSD, least-significant difference. Data pooled over herbicides and application rates (sulfentrazone: 0.14, 0.21, or 0.28 kg ai ha^{-1}; trifloxysulfuron: 0.015, 0.022, or 0.029 kg ha^{-1}).

[b] Percent control based on visual estimates (0 = no visual symptoms; 100 = complete plant death).

[c] Percent shoot-number reduction relative to nontreated.

viability reductions in false-green kyllinga rhizomes compared to purple nutsedge tubers. Regardless of year, trifloxysulfuron reduced false-green kyllinga rhizome viability by > 90%, whereas sulfentrazone reduced viability by 40 and 70% in 2007 and 2008, respectively. Reducing false-green kyllinga rhizome viability by > 90% would likely result in control in subsequent years. Single-year herbicide programs would likely not eradicate perennial sedge species; however, if practitioners are able to reduce rhizome viability, it may lend itself to reduced herbicide inputs in subsequent years.

Previous research suggests foliar-applied trifloxysulfuron distributes primarily in the treated leaf and primary shoot of false-green kyllinga; however, appreciable trifloxysulfuron is translocated to rhizomes and roots (McElroy et al. 2004). For herbicides inhibiting acetolactate synthase (ALS), absorption and translocation within the plant determines whole plant activity (Shaner and Singh 1997). Because branched chain amino acid pathways are most active in meristematic regions (Shaner and Singh 1997), ALS herbicide translocation to rhizomes is imperative for acceptable control or viability reduction.

Excluding false-green kyllinga in 2008, sequential sulfentrazone or trifloxysulfuron applied 6 WAIT enhanced purple nutsedge and false-green kyllinga control compared to a single application or a sequential applied 4 or 8 WAIT in 2007 and 2008 (Table 5). These data indicate sequential application timing may affect purple nutsedge and false-green kyllinga control with optimum control obtained with a sequential application applied 6 WAIT. In 2007, a sequential application applied 6 WAIT provided 63% purple nutsedge control whereas sequential applications applied 4 or 8 WAIT provided approximately 9 to 12% less control. Similarly, in 2008, a sequential application applied 6 WAIT provided 62% purple nutsedge control, but when sequential treatments were applied 8 WAIT, control was reduced to 29%. Increased control when sequential applications were applied 6 WAIT may have been due to allowing sedge species to regrow after the initial application, whereas 4 wk may not be adequate to observe regrowth from initial application. Regardless of year, single applications provided < 40% purple nutsedge control from the initial application.

In 2007, sulfentrazone or trifloxysulfuron applied sequentially 6 WAIT provided the greatest false-green kyllinga control (84%), whereas sequential treatments applied 4 or 8 WAIT provided approximately 14% less control (Table 5). Conversely, in 2008, timing of sequential application did not affect false-green kyllinga control, although treatments containing a sequential application provided greater false-green kyllinga control compared to a single application.

Shoot-number reduction followed similar trends as visual estimates of control (Table 5). Regardless of species or year, a sequential treatment applied 6 WAIT enhanced purple

Table 6. Influence of herbicide application rate on purple nutsedge or false-green kyllinga control and shoot-number reduction 12 WAIT.[a]

	CYPRO				KYLGR			
	Control[c]		Shoot-number reduction[d]		Control[c]		Shoot-number reduction[d]	
Herbicide rate[b]	2007	2008	2007	2008	2007	2008	2007	2008
	%							
Low	42	36	59	68	70	46	68	71
Medium	51	48	61	80	73	64	64	77
High	61	50	67	79	71	69	74	77
$LDS_{0.05}$	5	4	NS	9	NS	4	NS	6

[a] WAIT, weeks after initial treatment; CYPRO, purple nutsedge; KYLGR, false-green kyllinga; LSD, least-significant difference. Data pooled over herbicides and sequential application timings.

[b] Evaluated application rates: sulfentrazone (0.14, 0.21, or 0.28 kg ai ha^{-1}); trifloxysulfuron (0.015, 0.022, or 0.029 kg ha^{-1}).

[c] Percent control based on visual estimates (0 = no visual symptoms; 100 = complete plant death).

[d] Percent shoot-number reduction relative to nontreated.

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Table 7. Influence of sulfentrazone tank-mix partner on purple nutsedge control, shoot-number reduction and tuber viability 12 WAIT.[a]

Treatment[b]	Control[c]		Shoot-number reduction[d]		Tuber viability[e]	
	2007	2008	2007	2008	2007	2008
	%					
Halosulfuron + sulfentrazone	49	31	22	24	93	90
Sulfosulfuron + sulfentrazone	79	40	52	49	79	85
Trifloxysulfuron + sulfentrazone	42	38	43	44	84	74
Sulfentrazone	34	18	−20	19	83	88
Nontreated	0	0	–	–	100	100
$LSD_{0.05}$	10	6	57	30	13	9

[a] WAIT, weeks after initial treatment; CYPRO, purple nutsedge; LSD, least-significant difference. Data pooled over sulfentrazone and tank-mix partner rates.

[b] Evaluated application rates: sulfentrazone (0.28 or 0.42 kg ai ha^{-1}); halosulfuron (0.035 or 0.07 kg ha^{-1}); sulfosulfuron (0.033 or 0.066 kg ha^{-1}); trifloxysulfuron (0.015 or 0.029 kg ha^{-1}).

[c] Percent control based on visual estimates (0 = no visual symptoms; 100 = complete plant death).

[d] Percent shoot-number reduction relative to nontreated.

[e] Percent viability based on shoot emergence from harvested tubers that were planted in greenhouse.

nutsedge and false-green kyllinga shoot-number reduction compared to a single application. In 2007, a sequential applied 6 WAIT provided 75% purple nutsedge shoot-number reduction, similar to results attained with sequential applications applied 8 WAIT. In 2008, sequentials applied 4 or 8 WAIT provided comparable purple nutsedge shoot-number reductions, although a sequential application 8 WAIT was not as effective compared to a sequential applied 6 WAIT. Sequential application timing did not affect false-green kyllinga shoot-number reduction in 2007 or 2008. Little published data exist pertaining to the effect of sequential application timing for perennial Cyperaceae control with sulfentrazone or trifloxysulfuron, although much research has concluded a sequential trifloxysulfuron application is required for acceptable control (Brecke et al. 2007; McElroy et al. 2005b).

Excluding false-green kyllinga in 2007, control of false-green kyllinga and purple nutsedge improved with medium and high herbicide rates compared to low evaluated rates (Table 6). In 2007, purple nutsedge control increased by 10% as rate increased from low to medium and medium to high. In 2008, the medium rate provided similar control to that observed with the high rate. Similarly, Singh and Singh (2004) reported 42 or 63 g/ha trifloxysulfuron provided comparable yellow nutsedge control with rates greater than 21 g ha^{-1}. These data indicate that although low evaluated rates may not provide acceptable control, applying maximum application rates may not always provide greater control compared to medium rates.

In general, treatments provided greater control of false-green kyllinga than of purple nutsedge (Table 6). In 2007, there were no differences in false-green kyllinga control among the three rates evaluated (70 to 73%). Reduced rainfall in 2007 likely reduced false-green kyllinga growth and/or vigor, resulting in a similar response to all application rates. However, in 2008, control increased as rate increased with low, medium, and high rates providing 46, 64, and 69% control, respectively. Hutto et al. (2007) reported greater false-green kyllinga control with 0.42 compared to 0.28 kg ha^{-1}sulfentrazone, whereas McElroy et al. (2005b) reported similar control with 0.42 and 0.56 kg ha^{-1}.

In 2007, herbicide application rate did not significantly affect purple nutsedge or false-green kyllinga shoot-number reduction. In 2008, medium and high herbicide rates provided similar shoot-number reduction, which was greater than the low evaluated rate. It should be noted that the low evaluated rates were lower than the recommended application rate for Cyperaceae spp. (Anonymous 2010a to c).

Table 8. Influence of sulfentrazone tank-mix rate on purple nutsedge control and shoot-number reduction 12 WAIT.[a]

Tank-mix rate[b]	Control[c]		Shoot-number reduction[d]	
	2007	2008	2007	2008
	%			
0.5×	58	31	7	34
1×	55	42	29	44
$LSD_{0.05}$	NS	5	NS	NS

[a] WAIT, weeks after initial treatment; CYPRO, purple nutsedge; LSD, least-significant difference; NS, not significant. Data pooled over tank-mix partners.

[b] Evaluated tank-mix application rates (0.5 or 1×): sulfentrazone (0.28 or 0.42 kg ai ha^{-1}); halosulfuron (0.035 or 0.07 kg ha^{-1}); sulfosulfuron (0.033 or 0.066 kg ha^{-1}); trifloxysulfuron (0.015 or 0.029 kg ha^{-1}).

[c] Percent control based on visual estimates (0 = no visual symptoms; 100 = complete plant death).

[d] Percent shoot-number reduction relative to nontreated.

Herbicide Tank-Mix Partners with Sulfentrazone for Purple Nutsedge Control. In 2007 and 2008, single applications of sulfentrazone tank mixed with halosulfuron or trifloxysulfuron provided unacceptable ($<$ 50%) purple nutsedge control, and sulfentrazone tank mixed with sulfosulfuron provided greater control (79%) in 2007 (Table 7). Although control improved compared to sulfentrazone alone, tank mixes with halosulfuron, sulfosulfuron, or trifloxysulfuron provided $\leq$ 40% control in 2008. No shoot-number reduction differences were observed among tank-mix partners. In 2007, tank mixes with sulfosulfuron and trifloxysulfuron provided greater reductions in shoot number compared to sulfentrazone alone, and the halosulfuron tank mix was similar to sulfentrazone alone.

In 2007, tank-mix partners did not affect tuber viability compared to sulfentrazone alone (Table 7). In 2008, trifloxysulfuron tank mixed with sulfentrazone reduced purple nutsedge tuber viability compared to sulfentrazone alone, whereas tank-mix partners halosulfuron and sulfosulfuron did not. Although subtle differences were observed, tank-mix partner application rate did not affect purple nutsedge control or shoot-number reduction (Table 8). These data indicate sulfentrazone may not provide acceptable postemergence purple nutsedge control in bermudagrass areas and attempts to increase control with tank-mix partners are not consistent.

This research indicates sulfosulfuron or trifloxysulfuron can provide acceptable false-green kyllinga and purple nutsedge control in turf environments including bermudagrass, although repeat applications will likely be required. Weather conditions, particularly rainfall, affected perennial sedge control with evaluated herbicides. Sedge control varied up to 40% between 2007 and 2008, which the authors feel was due in large part to rainfall differences. Further, our results indicate that repeat applications applied 6 WAIT provided the highest level of control, whereas highest evaluated rates did not always enhance false-green kyllinga or purple nutsedge control compared to medium or low rates. Efforts to enhance purple nutsedge control with sulfentrazone timings, rates, and tank-mix partners were inconsistent. These data confirm sulfosulfuron or trifloxysulfuron offer acceptable perennial sedge control and may be incorporated into a comprehensive integrated pest management plan.

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