Tolerance of Native and Ornamental Grasses to Over-the-top Applications of Topramezone Herbicide

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Abstract. Research was conducted to determine the tolerance of multiple native and ornamental grass species and one ornamental sedge species to over-the-top applications of the postemergence herbicide topramezone at three locations in the southeastern United States in 2016 and 2017. Fully rooted liners of selected grass species were outplanted into research plots in Apopka, FL; Dallas, TX; and Knoxville, TN in late spring, allowed time to establish (≈ 1 –2 months) and then treated with two applications of topramezone at either 0.05 or 0.10 kg a.i./ha at 6–8 weeks intervals. Results showed that species including *Andropogon virginicus* (broomsedge), *Schizachyrium scoparium* ‘The Blues’ (little bluestem), *Tripsacum dactyloides* (eastern gamagrass), and *Tripsacum floridanum* (florida gamagrass) exhibited the greatest tolerance to topramezone with <10% injury to no injury being evident after each application of both herbicide rates tested. *Chasmanthium latifolium* (wild oats), *Eragrostis elliottii* ‘Wind Dancer’, *Muhlenbergia capillaris* (pink muhly), and *Spartina bakeri* (sandcord grass) were significantly injured (50% injury or greater) at both herbicide rates. Average injury observed on *Panicum virgatum* ‘Shenandoah’ (red switchgrass) (ranging from 39% to 100% injury) and *Sorghastrum nutans* (indian grass) (ranging from 0% to 40% injury) was higher in Florida than in Tennessee (injury ranging from 23% to 43% on red switchgrass and 0% to 10% on indian grass). Similarly, *Pennisetum alopecuroides* (dwarf fountain grass) showed higher tolerance in Texas (ranging from 0% to 34% injury) compared with those observed in Tennessee (ranging from 0% to 53% injury). Topramezone injury to *Carex appalachica* (appalachian sedge) was $\leq 18\%$ following two applications at both rates tested. Although no injury was observed in appalachian sedge following a single application up to 0.1 kg a.i. in Florida, plants succumbed to heat stress and accurate ratings could not be taken following the second application. Because of variability observed, tolerance of red switchgrass, indian grass, dwarf fountain grass, and appalachian sedge to applications of topramezone deserves further investigation. There is potential for future use of topramezone for control of certain grass and broadleaf weeds growing in and around certain ornamental grass species. However, as there was significant variability in tolerance based on species and differences in cultivars, testing a small group of plants before large-scale application would be recommended.

Ornamental and native grasses and grass-like species are becoming increasingly popular as landscape plants (Dana, 2002;

Ruter and Carter, 2000; Thetford et al., 2009). Numerous species are now widely available and can be selected to fit almost any need (e.g., aesthetic value, drought tolerance, and pest resistance) and many thrive in low-input landscapes (Thetford et al., 2009; Wilson and Knox, 2006, 2009). In addition to their low-maintenance characteristics, recent trends toward a more “naturalist” approach and landscape designs that feature predominately native plants have further increased the use and demand of ornamental or native grass species

(Brzuszek and Harkess, 2009; Ozguner and Kendle, 2006).

Golf courses typically have areas referred to as “natural areas,” which are areas on the course beyond the maintained rough (Dunning, 2014). These areas are often promoted for their ecological function (Nelson, 1997) but can present/pose design and maintenance issues for golf course superintendents (Dunning, 2014). These naturalized areas average 25.8 acres or about 17% of the total golf course area (Gelernter et al., 2017), creating a need for readily available, low-input, and aesthetically pleasing plant species in these spaces (Dunning, 2014; Florida Department of Environmental Protection, 2007). Ornamental and native grasses have been previously evaluated to determine their suitability and are now often used in these naturalized areas on golf courses (Dunning, 2014; Maddox et al., 2007; Voigt, 2002; Weston, 1990).

Although many of the most widely planted ornamental grass species are relatively resistant to disease, insect pests, or both (Thetford et al., 2009; Wilson and Knox, 2009), weed control continues to be a challenge for both landscape applicators and golf course superintendents managing large monocultures of ornamental grasses. Most of the research on ornamental grass tolerance to herbicide applications has focused on pre-emergence (PRE) herbicides labeled for use in container production. Research focusing on container-grown ornamental grasses has shown that many species are tolerant to over-the-top applications of common PRE herbicides including pendimethalin, prodiamine, isoxaben, and others (Cole and Cole, 2007; Glaze et al., 1980; Neal and Senesac, 1991). However, these herbicides would provide little benefit to areas already infested with weeds on golf courses or in landscapes.

A few studies have investigated the impacts of postemergence (POST) herbicides on ornamental grasses. Hubbard and Whitwell (1991) evaluated response of 12 ornamental grasses from nine genera to applications of three graminicides including fenoxaprop-ethyl, fluazifop-P-butyl, and sethoxydim. Significant injury, growth reduction, or both were noted among most species with all three herbicides with the exception of fenoxaprop-ethyl applications to *Calamagrostis arundinacea* ‘Karl Foerster’. The authors also reported a high degree of tolerance in two other *Calamagrostis* cultivars [*C. arundinacea* ssp. *brachytricha* (Steud.) Tzvel. and *Calamagrostis* $\times$ *acutiflora* (Schrad.) Reichenb. ‘Stricta’] to fenoxaprop-ethyl applications. Gilliam et al. (1992) evaluated the same graminicides for use in *Pennisetum alopecuroides* ‘Hameln’, *Cortaderia selloana* ‘Rosea’, *Miscanthus sinensis* ‘Purpureus’, and *M. sinensis* ‘Gracillimus’ and reported similar findings, at least some injury was noted on all four species with each herbicide. Similarly, Voigt and Reicher (2009) reported that *Pennisetum alopecuroides* was sensitive to POST applications of fenoxaprop. Everman et al.

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(2011) evaluated 10 and 18 herbicide treatments for efficacy on *Miscanthus × giganteus* (a biofuel crop) and *M. sinensis* (primarily planted as an ornamental), respectively, two species that have become naturalized and problematic weeds in Asia (Hakoyama et al., 1977; Sugiura et al., 1970). Results showed that imazethapyr, imazamox, and rimsulfuron were the most efficacious treatments on *M. sinensis*. *Miscanthus × giganteus* was most responsive to treatments of glyphosate, foramsulfuron, nicosulfuron, and imazamox, which all reduced above and below-ground biomass in comparison with the nontreated control group. Although these studies show that there may be certain POST herbicides that can be used in ornamental grass plantings, graminicides evaluated by Hubbard and Whitwell (1991) would not control broadleaf weed species. Herbicides evaluated by Everman et al. (2011) that did not provide control of *M. sinensis* would still have likely caused a high degree of injury to plants used for aesthetic purposes. To effectively control broadleaf and grassy weeds, additional POST options are needed for practitioners managing areas planted with ornamental grasses.

Topramezone is a new POST herbicide that controls susceptible species by inhibiting the enzyme 4-hydroxyphenylpyruvate dioxxygenase (HPPD) (Grossman and Ehrhardt, 2007) and was registered for use turfgrass in 2014. Similar to other HPPD inhibitors, susceptible weeds turn white in color because of chlorophyll loss and growth stops. Topramezone has become an important tool for turfgrass managers as it effectively controls crabgrass species (*Digitaria* spp.), goosegrass [*Eleusine indica* (L.) Gaertn.], and many different broadleaf weeds (Elmore et al., 2013; Soltani et al., 2012; Zhang et al., 2013). In addition to controlling notable annual broadleaf and grass species, previous research shows that topramezone could be potentially used to selectively control bermudagrass (*Cynodon dactylon*) in cool-season turfgrass (Brosnan et al., 2011; Brosnan and Breeden, 2013; Elmore et al., 2011). Mesotrione, another HPPD-inhibiting herbicide, has been shown to have little effect on growth of *M. sinensis* (Everman et al., 2011) or *P. alopecuroides* (Voigt and Richer, 2009). As topramezone has shown to be minimally injurious when applied to certain grass species (Johnston et al., 2016), it could be used as a selective POST herbicide for natural areas planted with ornamental grass species. The objective of this research was to evaluate the tolerance of ornamental grass species following over-the-top applications of topramezone.

Materials and Methods

Seventeen different native and ornamental grass species commonly planted in landscapes and golf course natural areas were evaluated for tolerance to topramezone applications in Apopka, FL; Knoxville, TN; and Dallas, TX, in 2016 and in Florida and

Tennessee in 2017 following landscape establishment (Table 1). In 2016, liners of *Spartina bakeria* (sandcord grass), *Tripsacum dactyloides* (eastern gamagrass), and *Tripsacum floridanum* (florida gamagrass) were obtained from EarthBalance® Nursery (Arcadia, FL), whereas all other species were obtained from Hoffman Nursery, Inc. (Rougemont, NC) for all three locations. Liners of all species were in 4- to 10-cm square pots (32- or 18-cell packs) that had fully rooted. In 2017, all liners were obtained from Hoffman Nursery. Uniform liners were used at all three locations.

Site conditions and planting. Florida trials were conducted at the Mid-Florida Research and Education Center in Apopka, FL. The experimental site was a fallow field with a Tavares-Millhopper fine sand (pH 6.2) that was rototilled and treated with a 2% glyphosate (Ranger Pro, Monsanto, St. Louis, MO) solution to control existing weeds. Selected species (Table 1) were transplanted on 19 Apr. 2016 into 1.8 × 4.3 m plots and received 2.5 cm irrigation via portable overhead sprinklers immediately after planting; plants were drip irrigated as needed for the remainder of the trial. In 2017, plants were transplanted on 31 May and irrigated similarly. In both years, Osmocote® Plus (15N–3.9P–9.9K) (ICL Specialty Fertilizers-North America, Dublin, OH) was broadcast to plots at 64 g formulated product per m². The experimental site in Tennessee was located at the East Tennessee Research and Education Center in Knoxville. Grasses were transplanted into a tilled and leveled Sequatchie silt loam soil (pH 6.2) on 19 Apr. 2016 and additional species on 19 May 2017. In Texas, grasses were planted into a Houston black clay loam soil (pH 8.0) at the Texas A&M AgriLife Center in Dallas, TX, on 13 May 2016. In Tennessee and Texas, plants were overhead irrigated immediately after planting and as necessary throughout the trial to prevent wilt, and no fertilizers were applied. At all sites and in both years, grasses were planted in rows with two plants of each species planted side by side on 0.6 m spacing. Plot sizes measured 1.8 × 4.3, 1.5 × 6.1, and 2.4 × 3 m in Florida, Tennessee, and Texas, respectively. In all sites, weed control was performed with an application of pendimethalin (Pendulum® 2G, BASF, Corp., Research Triangle Park, NC) at a rate of 224 kg of formulated product per hectare following planting.

Herbicide treatments. Topramezone (Pylex®, BASF Corp., Research Triangle Park, NC) was applied at all three locations at either 0.05 or 0.10 kg·ha⁻¹ (1- and 2-fold the maximum label rate, respectively). A second application using the same methods followed ≈6–8 weeks later (Table 2). Topramezone was applied with the addition of methylated seed oil at 0.5% by volume. In 2016, herbicide treatments were applied on 21 June and 2 Aug. in Florida, 24 May and 8 July in Tennessee, and 31 May and 9 Aug. in Texas. In 2017, applications were made on 28 June and 9 Aug. in Florida and 12 June and 10 July in Tennessee. Herbicide treatments were applied using CO₂ backpack sprayers. In

Florida, the sprayer was calibrated to deliver 187 L·ha⁻¹ at 138 kPa using 8004 flat-fan nozzles (TeeJet Technologies, Wheaton, IL). The sprayer in Tennessee was calibrated to deliver 374 L·ha⁻¹ via four, flat-fan 8002 XR nozzles (TeeJet Technologies) at 138 kPa. A similar sprayer was used in Texas and calibrated to deliver 412 L·ha⁻¹ through three AIXR8002 nozzles (TeeJet Technologies) at 276 kPa. Two passes were made to cover the entire plot area. In Florida and Tennessee, data collected included visual injury ratings on a scale of 0 to 100 in relation to nontreated controls with 0 = no injury, 20 = minimal acceptable injury, and 100 = complete plant death. Injury was rated based on the percent of the plant showing signs of bleaching (at early evaluation dates) and subsequent necrosis, stunting, or both at later evaluation dates. Ratings were conducted at 7, 14, 28, and 42 d after the first (DAFT) and second (DAST) herbicide treatments were applied. In Texas, similar ratings were taken at 11, 20, 30, 51, and 69 DAFT and at 13 and 30 DAST. In Florida, growth indices [(height + width 1 + width 2)/3] were taken at 42 DAST at trial conclusion in 2016 on all plants that had visible living foliage. At the conclusion of the 2017 trials in Florida and Tennessee, all plants were harvested for shoot dry weight analysis by cutting shoots at the soil line and drying in a forced air oven at 49 and 52 °C in Tennessee and Florida, respectively, to a constant weight.

Experimental design and analysis. At each location, experimental plots consisted of two plants of each grass species being evaluated planted side by side. Grass species were planted in rows within experiment plots and one plot was considered a replication. Species planting order was not randomized within plots. Trials at all three locations were randomized complete blocks with either four (Florida and Texas) or three (Tennessee) replications per herbicide treatment. Each species was analyzed separately. All injury data taken on comparable evaluation dates were subjected to a mixed-model analysis of variance in SAS® (SAS Institute, Cary, NC) to determine if the data could be pooled by location, or in the case of broomsedge and little bluestem, by year or location to determine the significance of topramezone rate on each grass species. Topramezone rate was considered a fixed effect, whereas location, year (where applicable), and block (nested within location) and interactions were considered random effects. Shoot dry weights and growth indices were analyzed similarly, but growth indices data were not tested for interactions because they were only collected in Florida in 2016. Treatment means were separated using Fisher's protected least significance difference test at *P* = 0.05. Phytotoxicity data collected at ≈14 d after each application and the last data collected either before the second application or at trial conclusion are presented for the sake of brevity.

Results

Because of significant location × treatment interactions on most evaluation dates,

Table 1. Native and ornamental grass species evaluated for tolerance to over-the-top applications of topramezone herbicide.

Tribe ²	Species and cultivar	Common name	Native status ³	Location ^x			
				2016		2017	
Andropogoneae	<i>Andropogon virginicus</i>	Broomsedge	N	–	TN	–	TN
	<i>Miscanthus sinensis</i>	Miscanthus	I	–	TN	TX	–
	<i>Miscanthus sinensis</i> ‘Purpurescens’	Purple miscanthus	I	–	–	FL	TN
	<i>Schizachyrium scoparium</i> ‘The Blues’	Little bluestem	N	FL	TN	TX	FL
	<i>Sorghastrum nutans</i>	Indian grass	N	–	–	–	FL
	<i>Tripsacum dactyloides</i>	Eastern gamagrass	N	FL	TN	–	–
	<i>Tripsacum floridanum</i>	Florida gamagrass	N	FL	–	TX	–
Cariceae	<i>Carex appalachica</i>	Appalachian sedge	N	–	–	–	FL
Chasmanthieae	<i>Chasmanthium latifolium</i>	Wild oats	N	FL	TN	TX	–
Cynodonteae	<i>Muhlenbergia capillaris</i>	Pink muhly	N	–	–	–	FL
	<i>Muhlenbergia capillaris</i> ‘White Cloud’	White cloud muhly	N	FL	TN	TX	–
Eragrostideae	<i>Eragrostis curvula</i>	Weeping lovegrass	I	–	–	–	FL
	<i>Eragrostis elliottii</i> ‘Wind Dancer’	Wind dancer lovegrass	N	FL	TN	TX	–
Paniceae	<i>Panicum virgatum</i> ‘Shenandoah’	Red switchgrass	N	FL	TN	–	–
	<i>Pennisetum alopecuroides</i> ‘Cassian’	Cassian fountain grass	I	–	–	–	FL
	<i>Pennisetum alopecuroides</i> ‘Hameln’	Dwarf fountain grass	I	–	TN	TX	–
Zysoiseae	<i>Spartina bakeri</i>	Sand cordgrass	N	FL	–	TX	–
	<i>Sporobolus heterolepis</i>	Prairie dropseed	N	–	TN	–	–

²Derived from Soreng et al. (2015) and Global Carex Group (2015).³Native status shows species which are native (N) or introduced (I) in North America. In cases where cultivars are listed, native status is shown for genus and species.^xTrials were conducted in Apopka, FL; Knoxville, TN; and Dallas, TX in 2016 and Apopka, FL, and Knoxville, TN, in 2017.

FL = Florida; TN = Tennessee; TX = Texas.

Table 2. Native and ornamental grass planting dates, and rainfall, temperature, relative humidity, and wind speed at herbicide² application times at three experimental locations.³

	2016			2017	
	Florida	Tennessee	Texas	Florida	Tennessee
Planting date	19 Apr.	19 Apr.	13 May	31 May	19 May
First application	21 June	24 May	31 May	28 June	12 June
First rainfall ^x	26 June (0.1)	26 May (0.2)	31 May (4.5)	29 June (0.3)	13 June (3.8)
Temp (C°)	30	19	24	27	28
Relative humidity (%)	53	65	81	81	67
Wind speed (m·s ⁻¹)	2.6	2.1	2.7	2.1	0
Second application	2 Aug.	8 July	9 Aug.	9 Aug.	10 July
First rainfall	4 Aug. (0.2)	8 July (1.8)	12 Aug. (0.1)	9 Aug. (0.5)	14 July (0.6)
Temp (C°)	33	27	33	30	17
Relative humidity (%)	67	74	57	71	99
Wind speed (m·s ⁻¹)	0	4.6	3.1	3.1	0

²Applications of topamezone (Pylex®, BASF, Corp.) at 0.05 or 0.10 kg·ha⁻¹ with addition of a methylated seed oil at 0.5% v:v.³Trials were conducted in Apopka, FL; Knoxville, TN; and Dallas, TX, in 2016 and in Apopka, FL, and Knoxville, TN, in 2017.^xFirst rainfall shows date and amount of rainfall received parenthetically (in cm).

differences in evaluation dates at the Texas location, and herbicide application and reapplication schedules relative to planting dates, results are presented separately for each location. No significant injury was observed on broomsedge, little bluestem, miscanthus, eastern gamagrass, or florida gamagrass at any location following two applications of topamezone at either rate (Tables 3 and 4). Growth indices collected at the Florida location showed no treatment effects on little bluestem, eastern gamagrass, or florida gamagrass treated with either rate of topamezone in comparison with nontreated plants (Table 3). In 2017, broomsedge treated with either rate of topamezone had similar or greater shoot dry weight as nontreated plants in Tennessee, but topamezone caused a 69% and 50% reduction in shoot dry weight relative to the nontreated control at the 0.05 and 0.10 kg a.i./ha rates, respectively (Table 4). Although no injury was observed on miscanthus in 2016, purple miscanthus did show signs of injury in 2017 (Table 4). In

Tennessee, significant injury was only observed at the high application rate following the first application but no significant injury or growth reductions were observed following the second. The reverse was true in Florida where no injury was observed after the first application. However, following the second application, topamezone caused 36% and 43% injury at the 0.05 and 0.1 kg a.i./ha rates, respectively, at 42 DAST, and shoot biomass was reduced 49% relative to the nontreated control (Table 4).

Appalachian sedge and indian grass were tolerant to topamezone in Tennessee (Table 4). Whereas some minor injury less than 10% in indian grass and 20% in appalachian sedge was noted at times, a full recovery was observed at 28 DAST and 42 DAST. A reduction in growth was noted in appalachian sedge treated at 0.10 kg·ha⁻¹ in Tennessee but no growth differences were observed in indian grass. In Florida, no injury was observed in appalachian sedge following the first application. Following the second

application, it became evident that plants were not establishing and began showing signs of stress. While no bleaching was observed following either the first or second herbicide application, accurate phytotoxicity ratings or growth data could not be recorded because of environmental stress. No injury was observed on indian grass in Florida after the first application. Following the second application, topamezone causes 34% and 40% injury with 0.05 and 0.1 kg a.i./ha rates, respectively, at 14 DAST. Shoot dry weight, at the trial conclusion, was reduced up to 60% with either topamezone rate when compared with the nontreated control (Table 4).

‘Wind Dancer’ lovegrass showed moderate tolerance to topamezone applied at the 0.05 kg a.i./ha rate in all three locations in 2016 (Table 3). Phytotoxicity ratings at 14 DAST were 53% in Tennessee but decreased to 7% by 42 DAST. Following the second application, injury at 14 DAST in Tennessee measured 23%, but the plants recovered and were similar to the nontreated controls by 42 DAST. In Florida and Texas, injury ranged from 8% to 50% when treated at the lower rate, but less recovery was noted. Growth indices in Florida showed ‘Wind Dancer’ lovegrass treated at the lower rate was similar in size to the nontreated control. Greater ‘Wind Dancer’ lovegrass injury was observed at the 0.10 kg·ha⁻¹ rate at all three locations on most evaluation dates. In 2017, weeping lovegrass was significantly injured by topamezone at both rates, especially following the second application when visual injury ratings exceeded 80% in both Tennessee and Florida (Table 4). Shoot dry weights were reduced 84% to 99% in Tennessee at the 0.05 and 0.1 kg a.i./ha rates, respectively, and more than 96% at both rates in Florida compared with the nontreated control following topamezone application.

Table 3. Native and ornamental grass injury ratings following over-the-top applications of topramezone in Florida, Tennessee, and Texas in 2016.

Species	Rate (kg·ha ⁻¹) ^y	Apopka, FL				Knoxville, TN				Dallas, TX					
		Mean injury ratings ^z				G.I. ^v	Mean injury ratings				Mean injury ratings				
		First application ^x		Second application ^w			First application		Second application		First application		Second application		
		14 DAT	42 DAT	14 DAT	42 DAT		14 DAT	42 DAT	14 DAT	42 DAT	11 DAT	69 DAT	13 DAT	30 DAT	
Broomsedge	0	—	—	—	—	—	—	0 ^u	0	0	0	—	—	—	—
	0.05	—	—	—	—	—	—	2	0	0	0	—	—	—	—
	0.10	—	—	—	—	—	—	0	0	0	0	—	—	—	—
Dwarf fountain grass	0	—	—	—	—	—	—	0 c	0	0 b	0 c	0	0 c	0 c	0 c
	0.05	—	—	—	—	—	—	30 b	0	53 a	17 b	11	0	6 b	15 b
	0.10	—	—	—	—	—	—	43 a	0	53 a	37 a	10	0	14 a	34 a
Eastern gamagrass	0	0	0	0	0	97.7 a	—	0	0	0	0	—	—	—	—
	0.05	0	0	0	0	94.2 a	—	0	0	0	0	—	—	—	—
	0.10	0	0	0	0	91.5 a	—	0	0	0	0	—	—	—	—
Florida gamagrass	0	0	0	0	0	68.8 a	—	—	—	—	—	0	0	0	0
	0.05	0	0	0	0	79.5 a	—	—	—	—	—	0	0	0	0
	0.10	0	0	0	0	74.1 a	—	—	—	—	—	0	0	0	0
Little bluestem	0	0	0	0	0	70.0 a	—	0	0	0	0	0	0	0	0
	0.05	0	0	0	0	65.1 a	—	0	0	0	0	0	0	0	0
	0.10	0	0	0	0	68.3 a	—	0	0	0	0	2	0	0	0
Wind Dancer lovegrass	0	0 c	0 b	0 b	0 c	140.1 a	—	0 c	0 b	0 b	0 b	0	0 b	0 b	0 b
	0.05	25 b	40 a	50 a	25 b	75.4 ab	—	53 b	7 b	23 a	3 b	8	17 b	18 b	23 ab
	0.10	33 a	54 a	56 a	33 a	54.9 b	—	70 a	20 a	40 a	13 a	8	49 a	60 a	45 a
Wild oats	0	0 b	15 b	10 b	0 b	31.7 a	—	0 c	0 b	0 b	0 b	0	0 b	0 c	0 b
	0.05	44 a	83 a	73 a	44 a	21.6 b	—	53 b	40 a	50 a	78 a	0	83 a	91 b	95 a
	0.10	49 a	88 a	80 a	49 a	22.5 b	—	60 a	53 a	70 a	87 a	0	96 a	99 a	98 a
Sand cordgrass	0	0 b	0 b	0 b	0 b	74.8 a	—	—	—	—	—	0	0 b	0 b	0 b
	0.05	39 a	98 a	100 a	100 a	0.0 b	—	—	—	—	—	0	81 a	84 a	91 a
	0.10	40 a	99 a	100 a	100 a	0.0 b	—	—	—	—	—	0	81 a	81 a	90 a
Red switchgrass	0	0 c	0 b	0 c	0 c	57.9 a	—	0	0	0 b	0 b	—	—	—	—
	0.05	39 b	59 a	74 b	85 b	33.5 b	—	23	3	10 ab	7 ab	—	—	—	—
	0.10	46 a	60 a	91 a	100 a	0.0 c	—	43	17	27 a	22 a	—	—	—	—
White cloud muhlygrass	0	0 b	0 c	0 c	0 b	97.4 a	—	0 b	0 b	0 c	0 b	0	0 c	0 c	0 b
	0.05	50 a	66 b	48 b	100 a	0.0 b	—	43 a	17 ab	37 b	47 b	0	48 b	47 b	73 a
	0.10	50 a	74 a	83 a	100 a	0.0 b	—	53 a	30 a	67 a	80 a	0	84 a	88 a	90 a
Miscanthus	0	—	—	—	—	—	—	0	0	0	0	0	0	0	0
	0.05	—	—	—	—	—	—	0	0	0	0	0	0	0	0
	0.10	—	—	—	—	—	—	10	0	2	10	0	0	0	0

^zVisual phytotoxicity (injury) ratings were taken on a scale of 0 to 100; 0 = no injury, 100 = complete death.^yRates = kg of active ingredient (topramezone) applied on a per hectare basis.^xFirst application was applied on 24 May, 21 June, and 31 May in TN, FL, and TX, respectively. DAT = days after treatment.^wSecond application was applied on 8 July, 2 Aug., and 9 Aug. in TN, FL, and TX, respectively.^vG.I. = growth index = [(plant height + width 1 + width 2)/3] in cm.^uMeans within a column for each species followed by the same letter are not significantly different according to Fisher's protected least significant difference ($P = 0.05$).

Table 4. Native and ornamental grass injury ratings following over-the-top applications of topramezone in Florida and Tennessee in 2017.

		Knoxville, TN					Apopka, FL					
		Mean injury ratings ^z				Shoot dry wt (g)	Mean injury ratings				Shoot dry wt (g)	
		First application ^x		Second application ^w			First application		Second application			
Species	Rate (kg·ha ⁻¹) ^y	14 DAT	28 DAT	14 DAT	42 DAT		14 DAT	42 DAT	14 DAT	42 DAT		
Appalachian sedge	0	0 ^v	0	0 b	0	17.7 a	0	0	—	—	—	
	0.05	2	0	7 b	0	20.7 a	0	0	—	—	—	
	0.10	2	0	18 a	0	9.7 b	0	0	—	—	—	
Broomsedge	0	0	0	0	0	723.0 b	0	0	0	0	243.5 a	
	0.05	0	0	0	0	907.0 a	0	0	0	0	75.6 b	
	0.10	0	0	0	0	678.7 b	0	0	0	0	120.7 b	
Cassian fountain grass	0	0 c	0 c	0 c	0 c	425.0 a	0 b	0 c	0 b	0 b	76.9 a	
	0.05	73 b	32 b	72 b	37 b	110.0 b	21 a	26 b	59 a	83 a	27.8 b	
	0.10	83 a	57 a	90 a	63 a	53.3 b	28 a	44 a	68 a	83 a	21.0 b	
Indian grass	0	0 b	0	0 b	0	1,250.7 a	0 b	0	0 b	0 b	195.5 a	
	0.05	2 b	0	10 a	0	1,257.0 a	11 a	0	34 a	28 a	77.7 b	
	0.10	10 a	0	10 a	0	1,184.7 a	13 a	0	40 a	33 a	86.4 b	
Little bluestem	0	0	0	0	0	162.7 b	0	0	0	0	118.7 a	
	0.05	0	0	0	0	321.3 a	0	0	0	0	60.0 a	
	0.10	0	0	0	0	323.0 a	0	0	0	0	109.5 a	
Pink muhly	0	0 c	0 b	0 b	0 b	212.3 a	0 c	0 c	0 b	0 b	188.9 a	
	0.05	10 b	5 b	73 a	83 a	50.0 b	23 b	38 b	86 a	98 a	8.2 b	
	0.10	42 a	23 a	92 a	94 a	15.3 b	43 a	71 c	93 a	95 a	8.5 b	
Purple miscanthus	0	0	0 b	0	0	132.7 a	0	0	0 b	0 b	13.4 a	
	0.05	23	33 ab	13	10	90.7 a	0	0	21 ab	36 a	6.9 b	
	0.10	27	43 a	10	0	100.0 a	0	0	35 a	43 a	6.8 b	
Weeping lovegrass	0	0 c	0 c	0 c	0 c	1,070.0 a	0 b	0	0 b	0 b	477.4 a	
	0.05	67 b	43 b	77 b	67 b	167.0 b	6 b	1	73 a	74 a	17.2 b	
	0.10	93 a	98 a	98 a	97 a	9.7 b	14 a	5	76 a	88 a	16.8 b	

^zVisual phytotoxicity (injury) ratings were taken on a scale of 0 to 100; 0 = no injury, 100 = complete death.^yRates = kg of active ingredient (topramezone) applied on a per hectare basis.^xFirst application was applied on 12 and 28 June in Knoxville and Apopka, respectively. DAT = days after treatment.^wSecond application was applied on 10 July and 9 Aug. in Knoxville, TN, and Apopka, FL, respectively.^vMeans within a column for each species followed by the same letter are not significantly different according to Fisher's protected least significant difference ($P = 0.05$).

Fig. 1. Temperature (°C), relative humidity (%), and rainfall (cm) recorded over the course of the trial in 2016 in Apopka, FL; Knoxville, TN; and Dallas, TX [(1.8 × °C) + 32 = °F]; 1 cm = 0.3937 inch.

Dwarf fountain grass was moderately tolerant to single applications of topramezone. In both Tennessee and Texas, this species fully recovered from the first application by 42 and 69 DAFT, respectively (Table 3). Injury ratings increased following the second application but did not exceed

37% by the end of the trial. In 2017, 'Cassian' fountain grass was significantly injured at both rates in Florida and Tennessee (Table 4). Shoot dry weights were reduced by 74% and 87% in Tennessee and by 63% and 73% in Florida at the 0.05 and 0.1 kg a.i./ha rates, respectively.

Red switchgrass showed different responses in Tennessee and Florida. In Tennessee, red switchgrass showed moderate tolerance to topramezone with acceptable injury ratings of ≤20% at the 0.05 kg a.i./ha rate after the first evaluation date (Table 3). Although 43% injury was noted at 14 DAFT,

Table 5. Summary of native and ornamental grass tolerance to over-the-top applications^z of topramezone herbicide at three locations in the southeastern United States.

Tolerance ^y	Species	Location ^x	Yr ^w	Crop tolerance summary ^v
High	Appalachian sedge ^u	FL and TN	2017	Acceptable injury ($\leq 20\%$) in TN and FL
	Broomsedge	FL and TN	2016, 2017	No injury or growth reduction in TN; growth reduction in FL at both rates
	Eastern gamagrass	FL and TN	2016	No injury or growth reduction
	Florida gamagrass	FL and TX	2016	No injury or growth reduction
	Little bluestem	FL, TN, and TX	2016, 2017	No injury or growth reduction
Moderate	Miscanthus	TN and TX	2016	Acceptable ($\leq 20\%$) injury in TN and TX
	Dwarf fountain grass	TN and TX	2016	Full recovery after one application with either rate. Unacceptable injury after the second application in TN (both rates) and TX (high rate)
	Indian grass	FL and TN	2017	Acceptable injury ($\leq 20\%$) in TN. Unacceptable injury in FL after the second application
	Purple miscanthus	FL and TN	2017	Recovery in TN after two applications; no injury in FL after one application
	Red switchgrass	FL and TN	2016	Recovery in TN at 0.05 kg a.i./ha rate applied twice; unacceptable injury in FL
Low	Weeping lovegrass	FL and TN	2017	Acceptable injury ($\leq 20\%$) in TN after one application; unacceptable injury in FL
	Cassian fountain grass	FL and TN	2017	Unacceptable injury and growth reduction at both rates
	Pink muhly	FL and TN	2017	Unacceptable injury and growth reduction in TN after two applications; unacceptable injury in FL after one application and growth reduction
	Sand cordgrass	FL and TX	2016	Unacceptable injury and growth reduction at both rates
	White cloud muhlygrass	FL, TN, and TX	2016	Unacceptable injury and growth reduction at both rates
	Wind dancer lovegrass	FL, TN, and TX	2016	Unacceptable injury and growth reduction at both rates
	Wild oats	FL, TN, and TX	2016	Unacceptable injury and growth reduction at both rates

^zTopramezone was applied over the top at either 0.05 or 0.10 kg a.i./ha twice ≈ 6 –8 wk apart at each location in both years.

^yHigh tolerance shows species in which mean injury ratings never exceeded 20% on a 0% to 100% scale throughout the trial. Moderate tolerance shows species where injury was variable depending on rate, or number of applications. Low tolerance species are those that showed unacceptable injury ($>20\%$) after one application at 0.05 kg a.i./ha.

^xTrials were conducted in Apopka, FL; Knoxville, TN; and Dallas, TX in 2016 and in Apopka, FL, and Knoxville, TN, in 2017.

^wIn 2016, growth was assessed only in FL. In 2017, growth was assessed in both FL and TN.

^vWhere location is not noted, results refer to all experimental sites.

^uData were not collected at the Florida location following the second application because of plant stress.

FL = Florida; TN = Tennessee; TX = Texas.

Fig. 2. Temperature ($^{\circ}\text{C}$), relative humidity (%), and rainfall (cm) recorded over the course of the trial in 2017 in Apopka, FL and Knoxville, TN [$(1.8 \times ^{\circ}\text{C}) + 32 = ^{\circ}\text{F}$]; 1 cm = 0.3937 inch.

no statistically significant differences were detected among treatments. By 14 or 42 DAST in Tennessee, no differences were observed in red switchgrass treated at $0.05 \text{ kg} \cdot \text{ha}^{-1}$ and the nontreated control; visual injury ranged from 7% to 10% (Table 3). By contrast, red switchgrass in

Florida was significantly injured at both rates with injury increasing at the higher rate. By 42 DAST, all plants treated at the 0.10 kg a.i./ha rate were dead and plants treated with the lower rate had a mean injury rating of 85% and a lower growth index than nontreated plants (Table 3). Different results at the two locations

may have been due to environmental differences (Fig. 1) as warmer temperatures in Florida could have caused a higher degree of injury in this species.

Topramezone caused significant injury to wild oats at all three locations at both rates (Table 3). At all three locations,

phytotoxicity ratings ranged from 40% to more than 90% with ratings generally increasing following the second application and increasing with rate (Table 3). Injury ratings in Florida and Texas tended to be higher than those in Tennessee, possibly because of higher temperatures during the trial (Fig. 1) that are not ideal for this species (Wilson, 2011). Higher temperatures may have also caused the 10% to 15% injury noted in wild oats in Florida at 42 DAFT and 14 DAST.

Both muhlygrass species showed a high degree of sensitivity to both rates of topramezone at all three locations (Tables 3 and 4). For white cloud muhlygrass, less injury was observed in Tennessee compared with Florida and Texas where many (Texas) or all (Florida) plants died following the second application (Table 3). In 2017, severe injury or death was observed in muhlygrass treated in both Florida and Tennessee (Table 4). Regardless of rate, significant injury was also observed on sand cordgrass in both Florida and Texas on all evaluation dates other than 11 DAFT in Texas (Table 3). All sand cordgrass treated with topramezone died following the second application in Florida and had injury ratings $\geq 87\%$ in Texas by the end of the experiment.

Discussion

Based on results in this experiment, it is evident that appalachian sedge, broomsedge, eastern gamagrass, florida gamagrass, little bluestem, and miscanthus were highly tolerant of topramezone (Table 5). Broomsedge was highly tolerant in Tennessee in both years with no growth differences observed in 2017. No injury was observed in Florida in 2017 but reductions in shoot dry weight were noted at both rates. Appalachian sedge warrants additional research as it showed tolerance in Tennessee but Florida is outside of its native and preferable growing range (United States Department of Agriculture, Natural Resource Conservation Service, 2017), and the high temperatures (Fig. 2) and sandy soils were not conducive to accurate evaluations at later dates. However, it would seem likely that a true sedge species would be highly tolerant topramezone.

Dwarf fountain grass, indian grass, purple miscanthus, red switchgrass, and weeping lovegrass were moderately tolerant to topramezone with results differing based on location, topramezone rate, or number of applications. Dwarf fountain grass recovered following one application with either rate but higher injury was observed following the second application, most notably at the 0.10 kg a.i./ha rate. Acceptable ($\leq 20\%$) injury was observed on indian grass in Tennessee throughout the trial and in Florida after the first application, but injury occurred in Florida after the second application. Red switchgrass showed recovery to an acceptable level in Tennessee at the 0.05 kg a.i./ha rate but not in Florida. Similarly, purple miscanthus and weeping lovegrass results were also variable

depending on location and generally tolerated one application of either rate but not two. The acceptable level of injury in a landscape or golf course natural area will be highly variable depending on managers of these sites, clientele expectations, visibility of the area, available resources, and other factors. Topramezone would likely not be suitable alternative for species classified as moderately tolerant if used in a highly managed or visible site, but it could be a potential option in less visible areas or in cases where more injury could be tolerated because of high weed pressure. Further work may also be needed to refine sequential application strategies on this species.

Significant injury was observed in wild oats, both muhlygrass species, 'Cassian' fountain grass, both lovegrass species, and sand cordgrass in at least two locations on multiple evaluation dates; therefore, alternative herbicides should be chosen for natural areas containing these species. Whereas some injury was noted on dwarf fountain grass, the most severe injury was typically noted when topramezone was applied at a higher rate and this species showed few differences in terms of growth or injury ratings when comparing the label rate of topramezone to non-treated plants. Dwarf fountain grass also generally showed a high level of tolerance following a single application of either rate as it recovered quickly.

There is potential for future use of topramezone for control of certain grass and broadleaf weeds growing in and around certain ornamental grass species. As species were chosen based on popularity and use in landscapes and golf courses, it is difficult to make inferences concerning grass tolerance based on tribe or other higher classifications (Table 1). However, a few trends were noted including both *Tripsacum* spp. (eastern and florida gamagrass) showing a high degree of tolerance and both *Muhlenbergia capillaris* 'Pink' and *M. capillaris* 'White Cloud' showing a high degree of sensitivity. Whereas trends were noted with *Tripsacum* and *Muhlenbergia*, differences in tolerance were noted in *P. alopecuroides* between 'Cassian' and 'Hameln' and in *M. sinensis* and *M. sinensis* 'Pupurescens', albeit in different years. Because of this variability with certain species and/or cultivars, testing a small group of plants before large-scale application would be recommended.

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