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

S. Christopher Marble
Department of Environmental Horticulture, University of Florida, Institute of Food and Agricultural Sciences, Mid-Florida Research and Education Center, 2725 South Binion Road, Apopka, FL 32703; and Department of Plant Sciences, University of Tennessee, 2431 Joe Johnson Drive, Knoxville, TN 37996

Matthew T. Elmore
Department of Plant Biology, School of Environmental and Biological Sciences, Rutgers, The State University of New Jersey, 59 Dudley Road, New Brunswick, NJ 08901

James T. Brosnan
Department of Plant Sciences, University of Tennessee, 2431 Joe Johnson Drive, Knoxville, TN 37996

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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 (broomsgedge), 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 leptochloa ‘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 ≤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 for use in 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.

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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; Sugiuira 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 non-treated control group. Although these studies show that there may be certain POST herbicides that can be used in ornamental grass plantings, granicides 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 dioxygenase (HPPD) (Grossman and Elharrad, 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 stop. 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 (Cydonia dactylon) in cool-season turfgrass (Brosnan et al., 2011; Brosnan and Broedon, 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. (Rougmont, 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 roto-tilled 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, Osmosteoro 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 (PendulumÆ 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 (Teeket Technologies, Wheaton, IL). The sprayer in Tennessee was calibrated to deliver 374 L ha⁻¹ via four, flat-fan 8002 XR nozzles (Teeket Technologies) at 138 kPa. A similar sprayer was used in Texas and calibrated to deliver 412 L ha⁻¹ through three AIXR8002 nozzles (Teeket 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 non-treated 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 DAST 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<Sup>®</Sup> (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* | Species and cultivar | Common name | Native status* | Location* |
|--------|----------------------|-------------|----------------|-----------|
| Andropogoneae | *Andropogon virginicus* | Broomsedge | N | 2016 | 2017 |
| | *Miscanthus sinensis* | Miscanths | I | FL | TN | TX |
| | *Miscanthus sinensis ‘Purpureascens’* | Purple miscanths | I | FL | TN | TX |
| | *Schizachyrium scoparium ‘The Blues’* | Little bluestem | N | FL | TN | TX |
| | *Sorghastrum nutans* | Indian grass | N | FL | TN | TX |
| | *Tripsacum dactyloides* | Eastern gamagrass | N | FL | TN | TX |
| | *Tripsacum floridum* | Florida gamagrass | N | FL | TN | TX |
| Cariceae | Carex appalachica | Appalachian sedge | N | FL | TN | TX |
|  | Carex pratensis | Prairie dropseed | N | FL | TN | TX |
|  | Carex viridula | Wild oat | N | FL | TN | TX |
| Cyperaceae | *Muhlenbergia capillaris* | Pink muhly | N | FL | TN | TX |
|  | *Muhlenbergia capillaris ‘White Cloud’* | White cloud muhly | N | FL | TN | TX |
| Eragrostis | *Eragrostis curvula* | Weeping lovegrass | I | FL | TN | TX |
|  | *Eragrostis eliottii ‘Wind Dancer’* | Wind dancer lovegrass | N | FL | TN | TX |
| Paniceae | *Panicum virgatum ‘Shenandoah’* | Red switchgrass | N | FL | TN | TX |
|  | *Pennisetum alopecuroides ‘Cassian’* | Cassian fountain grass | I | FL | TN | TX |
| Pennisetum | *Pennisetum alopecuroides ‘Hameln’* | Dwarf fountain grass | I | FL | TN | TX |
| Zyzaceae | *Spartina bakeri* | Sand cordgrass | N | FL | TN | TX |
|  | *Sporobolus heterolepis* | Prairie dropseed | N | FL | TN | TX |

*Derived from Soreng et al. (2015) and Global Carex Group (2015).

*Native 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.

*Trials were conducted in Apopka, FL; Knoxville, TN; and Dallas, TX in 2016 and in 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 herbicide application times at three experimental locations.7

| Location | 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* | 26 June (0.1) | 26 May (0.2) | 31 May (4.5) | 29 June (0.3) | 13 June (3.8) |
| Temp (°C) | 30 | 24 | 27 | 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 |

*Applications of topramezone (Pylex®, BASF, Corp.) at 0.05 or 0.1 kg·ha⁻¹ with addition of a methylated seed oil at 0.5% v/v.

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*First rainfall shows date and amount of rainfall received parenthetically (in cm).

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| Temp (°C) | 30 | 24 | 27 | 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 |

*Applications of topramezone (Pylex®, BASF, Corp.) at 0.05 or 0.1 kg·ha⁻¹ with addition of a methylated seed oil at 0.5% v/v.

*Trials were conducted in Apopka, FL; Knoxville, TN; and Dallas, TX in 2016 and in Apopka, FL, and Knoxville, TN, in 2017.

*First rainfall shows date and amount of rainfall received parenthetically (in cm).

Differences in evaluation dates at the Texas location, and herbicide application and reaplication 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 topramezone 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 topramezone in comparison with nontreated plants (Table 3). In 2017, broomsedge treated with either rate of topramezone had similar or greater shoot dry weight as nontreated plants in Tennessee, but topramezone caused a 69% and 50% reduction in shoot dry weight relative to the nontreated control at the 0.05 and 0.10 kg·ha⁻¹ 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, topramezone caused 36% and 43% injury at the 0.05 and 0.1 kg·ha⁻¹ 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 topramezone 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 DAFT 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, topramezone causes 34% and 40% injury with 0.05 and 0.1 kg·ha⁻¹ rates, respectively, at 14 DAST. Shoot dry weight, at the trial conclusion, was reduced up to 60% with either topramezone rate when compared with the nontreated control (Table 4). 

‘Wind Dancer’ lovegrass showed moderate tolerance to topramezone applied at the 0.05 kg·ha⁻¹ 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 topramezone 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·ha⁻¹ rates, respectively, and more than 96% at both rates in Florida compared with the nontreated control following topramezone 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) | Apopka, FL Mean injury ratings | Knoxville, TN Mean injury ratings | Dallas, TX Mean injury ratings |
|--------------------------|----------------|-------------------------------|----------------------------------|--------------------------------|
|                          | 14 DAT | 42 DAT | 14 DAT | 42 DAT | 42 DAT | 14 DAT | 42 DAT | 14 DAT | 42 DAT |
| Broomsedge               | 0.00   | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      |
| Dwarf fountain grass     | 0.00   | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      |
| Eastern gamagrass        | 0.00   | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      |
| Florida gamagrass        | 0.00   | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      |
| Little bluestem          | 0.00   | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      |
| Wind Dancer lovegrass   | 0.00   | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      |
| Wild oats                | 0.00   | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      |
| Sand cordgrass           | 0.00   | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      |
| Red switchgrass          | 0.00   | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      |
| White cloud muhlygrass   | 0.00   | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      |
| Miscanthus               | 0.00   | 0      | 0      | 0      | 0      | 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. 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).
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,
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 kg·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. Tropamezone 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 DAF and 14 DAST.

Both muhlygrass species showed a high degree of sensitivity to both rates of topramezone at all 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 ≥87% in Texas by the end of the experiment.

**Discussion**

Based on results in this experiment, it is evident that appalachian sedge, broomseed, eastern gamagrass, florida gamagrass, little bluestem, and misanthus 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 misanthus, 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 (≤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 misanthus 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 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 recommend 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 where noted with Tripsacum and Muhlenbergia, differences in topramezone were noted in P. alopecuroides between ‘Cassian’ and ‘Hamel’ and in M. sinensis and M. sinensis ‘Pupuresscen’, 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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