Tolerance of Three Deep South Non-turf Ornamental Groundcovers to Applications of Postemergence Herbicides[1]

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Abstract

Ornamental groundcovers are a popular alternative to turfgrass in landscapes due to their low maintenance requirements, pest resistance, and shade tolerance. Weed control is a challenge in these groundcovers because few herbicide options are available. The objective of this research was to determine the tolerance of the groundcovers Asiatic jasmine [*Trachelospermum asiaticum* (Nakai) 'Minima'], perennial peanut [*Arachis pintoi* (Krapov.& W.C. Greg.) 'Golden Glory'] and dwarf mondo grass [*Ophiopogon japonicus* (L.f.) Ker Gawl.] 'Nana'] to herbicides, including bentazon, clopyralid, fluazifop-P-butyl, glufosinate, halosulfuron, imazaquin, sethoxydim, sulfentrazone, and sulfosulfuron applied at approximately 2 times the label rate. Asiatic jasmine and perennial peanut were evaluated in Apopka, FL and dwarf mondo grass was evaluated in Mobile, AL. Bentazon, clopyralid, glufosinate, glyphosate, and sulfosulfuron caused unacceptable injury and/or a reduction in shoot growth for all three species while fluazifop-P-butyl and sethoxydim caused no injury to any species. Halosulfuron caused minor injury but significantly reduced growth of dwarf mondo grass. Sulfentrazone caused no injury to Asiatic jasmine or perennial peanut but caused severe injury to dwarf mondo grass after only one application. Similarly, imazaquin caused only minor injury to Asiatic jasmine and dwarf mondo grass but significantly reduced growth of perennial peanut after two applications.

Index words: Postemergence herbicides, groundcovers, mondo grass, perennial peanut, Asiatic jasmine.

Chemicals used in this study: Bentazon (Basagran® T/O), 3-(1-methylethyl)-1H-2, 1,3-benzothiadiazin-4(3H)-one 2,2-dioxide, clopyralid (Lontrel), 3,6-dichloro-2pyridinecarboxylic acid, fluazifop-P-butyl (Fusilade® II), (2R)-2-[4-[[5-(trifluoromethyl)-2-pyridinyl]oxy]phenoxy]propanoic acid, Glufosinate (Finale®), 2-amino-4-(hydroxymethylphosphinyl)butanoic acid, Glyphosate (Ranger® PRO), *N*-phosphonomethyl)glycine, Halosulfuron-methyl (SedgeHammer®), methyl 3-chloro-5-[[[[4,6-dimethoxy-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]-1-methyl-1*H*-pyrazole-4-carboxylate, Imazaquin (Sceptor® T&O), 2-[4,5-dihydro-4-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-3-quinolinecarboxylic acid, Sethoxydim (Sethoxydim SPC), 2-[1-ethoxyimino)butyl]-5-[2-(ethylthio)propyl]-3-hydroxy-2-cyclohexen-1-one, Sulfentrazone (Dismiss®), N-[2,4-dichloro-5-[4-difluoromethyl)-4,5-dihydro-3-methyl-5-oxo-1H-1,2,4-triazol-1-yl]phenyl]methanesulfonamide, Sulfosulfuron (Certainty®), 1-(4,6-dimethoxypyrimidin-2-yl)-3-[(2-ethanesulfonyl-imidazo[1,2-a]pyridine-3-yl]sulfonylurea.

Species used in this study: Asiatic jasmine 'Minima' (*Trachelospermum asiaticum* 'Minima'), perennial peanut (*Arachis pintoi* 'Golden Glory'), dwarf mondo grass (*Ophiopogon japonicus 'Nana'*).

Significance to the Horticulture Industry

Ornamental groundcovers have become a popular alternative to turfgrass due to reduced maintenance costs and low fertility and irrigation needs. While groundcovers are often resistant to pest infestations, weed control is a continual challenge for landscape maintenance professionals due to limited postemergence herbicide options. The objective of this research was to determine the tolerance of three commonly grown ornamental groundcover species [Asiatic jasmine (*Trachelospermum asiaticum* 'Minima')], dwarf mondo grass (*Ophiopogon japonicas* 'Nana'), and perennial peanut (*Arachis pintoi* 'Golden Glory') to ten different postemergence herbicides. Results showed that herbicides including sethoxydim, fluazifop-P-butyl, sulfentrazone, and halosulfuron were generally not injurious to any of the three species, with the exception that sulfentrazone caused significant injury to dwarf mondo grass and halosulfuron reduced shoot weight in mondo grass. Bentazon application did not result in injury to perennial peanut but caused injury to Asiatic jasmine and dwarf mondo grass. Glyphosate and glufosinate caused significant injury to all three species. This information provides landscape managers with herbicide options that could be used for postemergence weed control in these species and information on which herbicides were or were not injurious.

Introduction

Turfgrass is the predominate groundcover in urban and suburban landscapes, with an estimate 13 to 20 million ha (32 to 49 million acres) in the Unites States (Milesi et al. 2005). While turfgrass offers numerous health, recreational, environmental, and aesthetic benefits (Beard and Green 1994), it is not suitable for all landscape situations. In cases where sunlight is limited or where steep slopes prevent or limit the ability to mow, low-growing groundcovers may be a suitable alternative. In recent years, homeowners have

[1]Received for publication December 27, 2019; in revised form April 16, 2020. This research was supported in part by a grant from the Florida Nursery Growers and Landscape Association (FNGLA). The contents of this manuscript are solely the responsibility of the authors and do not necessarily represent the views of FNGLA.

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also begun to opt for lower maintenance groundcovers in order to reduce maintenance costs, such as fertilization, irrigation, or mowing, or reduce the impact they feel their lawn may have on the environment (Ghimire et al. 2019). In Florida, turfgrass maintenance, most notably fertilization practices, have become an increasingly controversial issue, leading to blackout dates and implementation of numerous fertilization ordinances (Ryan et al. 2019). These concerns, as well as an increasing awareness of water scarcity and/or conservation efforts, have led many homeowners to opt for non-turf groundcovers because of the reduced need for irrigation and fertilization (Hayden et al. 2015, Pittenger et al. 2001, Shober et al. 2014).

While different groundcover species may be favored due to their lower nitrogen requirements or reduced irrigation needs, another benefit is the increased tolerance or resistance to insect or disease infestations (Garber and Bondari 1996). While arthropod or pathogenic pests can be limited or avoided with the use of groundcovers, weed management is still a major concern due to limited herbicide options (Marble et al. 2015). While some herbicide options have been investigated, most researchers opt to evaluate groundcovers for their weed suppressive abilities in hopes of avoiding weed problems. In a report by Eom et al. (2005), species including Lady's mantle [*Alchemilla mollis* (Buser) Rothm.], catmint [*Nepeta* × *faassenii* Bergmans ex. Stearn], moss phlox (*Phlox subulata* L.) and dwarf goldenrod (*Solidago sphacelata* Raf.) were strongly weed suppressive, providing reductions in weed establishment by over 90% in comparison with other groundcover species evaluated, such as yellow archangel [*Lamiastrum galeobdolon* (L.) Crantz]. Similar results have been reported with other species, including New Zealand burrs (*Acaena inermis* Hook.f.) and creeping wire vine [*Muhlenbeckia axillaris* (Hook.f.) Walp.] (Foo et al. 2011).

Although some groundcovers can eventually suppress weeds, their ability to do is often only realized once established, and weed control during establishment is especially difficult (Lugo-Torres et al. 2010). Plant spacing, species, growth rate and season during installation all have a significant effect on groundcover establishment time, and subsequently a significant effect on weed infestation (Quigley 2003). In cases where slower-growing groundcovers are used or when weed density is especially high, weeds are likely to outcompete groundcovers and create maintenance challenges going forward. It is common for landscape maintenance contractors to get new clients with heavily weed-infested groundcovers, and so options for both preemergence and postemergence herbicides are needed.

In the deep south U.S., three of the most commonly used groundcovers include Asiatic jasmine, mondo grass, and perennial peanut. Asiatic jasmine is a vine-like evergreen used extensively throughout the southeastern U.S. because it is drought tolerant, requires little fertilization, and is considered very low maintenance (Gilman 1999b). Mondo grass is not used as extensively as Asiatic jasmine, but is another popular evergreen groundcover, spreading by rhizomes with grass like foliage and high sun, shade and salt tolerance (Gilman 1999a). The term perennial peanut is used to refer to two very similar *Arachis* species that are commonly used in the landscape industry, *A. glabrata* and *A. pintoi*. The primary difference in these two species is that *A. glabrata* spreads by rhizomes and *A. pintoi* spreads by stolons. Both species are very similar in appearance with highly valued yellow flowers throughout much of the year in tropical or subtropical environments and have the same cultural and maintenance requirements (Rouse et al. 2004). Perennial peanut is primarily valued for its ornamental appeal and reduced maintenance requirements as it does not require N fertilization, is drought tolerant, and does not require mowing in most instances (Rouse et al. 2004).

Due to their prevalence in the landscape, herbicide options for Asiatic jasmine, mondo grass, and perennial peanut have been investigated previously. Asiatic jasmine has been shown to be tolerant to a wide range of preemergence herbicides and is currently listed on 10 preemergence herbicide labels as being tolerant (Neal et al. 2017). In experiments conducted by Davies and Duray (1992), granular herbicides including oxyfluorfen, oxadiazon, pendimethalin, metolachlor, pendimethalin, dithiopyr, prodiamine and spray-applied formulations of isoxaben + oryzalin had minimal to no effect on Asiatic jasmine rooting or growth in nursery containers. In addition to many preemergence herbicides, some postemergence herbicides are also labeled for over the top applications to Asiatic jasmine, including imazaquin (as Sceptor T/O®), sulfosulfuron (as Certainty®), and graminicides including clethodim, fluazifop-P-butyl, and sethoxydim (as Envoy®, Fusilade® II, and Segment® II, respectively) (Neal et al. 2017). While imazaquin and sulfosulfuron have efficacy on some broadleaf weeds, they are primarily used for sedge management as they have limited activity on many important broadleaf species (Shaner 2014). Other reports show that Asiatic jasmine is relatively tolerant to glyphosate, with injury only observed during periods of active growth or following multiple applications (Hoogmoed et al. 2013). Additional reports indicate herbicides including nicosulfuron, penoxsulam, sulfentrazone, and trifloxysulfuron cause no significant phytotoxicity, suggesting that more herbicides could potentially be used for selective weed control in Asiatic jasmine beds (Walsworth and Bush 2006).

Less research is available on mondo grass tolerance to herbicides, but *Ophiopogon* species are listed as a tolerant species for application on 15 preemergence herbicide labels and three postemergence herbicide labels including bentazon (as Basagran® T/O), clethodim, and sethoxydim. Similar to Asiatic jasmine, glyphosate has been evaluated as an over-the-top application to mondo grass, with tolerance observed following a single application at 1.12 kg ai· ha^{-1} (1 lb ai· A^{-1}). However, injury was observed at higher rates or following multiple applications (Hoogmoed et al. 2012). As mondo grass is relatively slow to establish, finding non-injurious and effective pre- and postemergence herbicides would be very advantageous to landscape maintenance professionals as weeds often invade new

plantings and become established before mondo grass can fill in and begin to outcompete weeds.

Most work on perennial peanut tolerance to herbicides has been conducted with *A. glabrata* and has focused on herbicides labeled for use in pastures because it is a common livestock forage. In an evaluation of postemergence herbicides regularly used in pasture weed management, dicamba, 2,4-D, and hexazinone were reported to be injurious while imazapic, imazamox, and 2,4-DB caused no injury or yield loss (Ferrell et al. 2006). While no ornamental perennial peanut species is listed on any pre- or postemergence herbicide label, authors have recommended use of graminicides such as sethoxydim, fluazifop-P-butyl, or clethodim for grassy weed control and bentazon for control of yellow nutsedge (*Cyperus esculentus* L.), as these herbicides have been reported to cause no injury (Rouse et al. 2004). Although data on perennial peanut tolerance to preemergence herbicides is limited, one previous study has reported no injury to *A. pintoi* perennial peanut during establishment following applications of oxyfluorfen + prodiamine, dimethenamid-P + pendimethalin, or trifluralin + isoxaben when applied as a granular formulation (Stamps et al. 2012). While spray-applied indaziflam (suspension concentrate formulation) was injurious at label rates, granular formulations of indaziflam have caused no injury or growth decrease in established *A. pintoi* or *A. glabrata* perennial peanut when applied at recommended label rates (Marble, unpublished data). Dimethenamid-P has also been shown to be non-injurious when applied as an emulsifiable concentrate formulation both during and after establishment (Torres et al. 2010).

Although several different pre- and postemergence herbicides have been evaluated for use in Asiatic jasmine, mondo grass, and perennial peanut, more options are needed due to limited tolerance with some of these chemicals and the lack of registrations. In addition, more options give landscapers the ability to rotate between herbicides with different modes of action to prevent resistance development. Further, many of the previously evaluated options are not currently registered for use in landscape planting beds. Preemergence herbicides are generally not injurious, but fewer options are available for postemergence control. As landscape managers often gain new clients with groundcover areas already infested with weeds, additional postemergence options are needed, especially when considering that few options are available for broadleaf weed control and many of the herbicides that have been evaluated previously on these species are not labeled for use in landscape planting beds. Further, most of the postemergence herbicide research that has been done has been carried out on established groundcovers when plants are least susceptible to herbicide injury and weed control is not as critical. The objective of this research was to evaluate the tolerance of Asiatic jasmine, mondo grass, and perennial peanut to repeated applications of postemergence herbicides commonly used in landscapes in the deep south U.S. Focus was placed on determining tolerance of these species to herbicide applications immediately after transplanting. Because landscape-grown ornamentals often show greater tolerance to herbicides compared with container-grown plants (Marble, unpublished data), all experiments were carried out on container-grown plants with the goal of also determining herbicide tolerance in nursery production scenarios.

Materials and Methods

Research trials were conducted at the Mid-Florida Research and Education Center in Apopka, FL and the Ornamental Horticulture Research Center in Mobile, AL in 2019. In Apopka, fully-rooted 5 cm (2-inch) 36-cell pack liners of Asiatic jasmine (*Trachelospermum asiaticum* 'Minima') and perennial peanut (*Arachis pintoi* 'Golden Glory') were obtained from a local nursery grower and transplanted into 3.0 L (trade gallon) containers on April 1. The substrate used was a 70:30:10 pine bark:peat:sand substrate (v:v:v) that had been previously amended with a controlled release fertilizer (17-5-11, 12-14 month) (Osmocote® Blend, ICL Specialty Fertilizers, Dublin, OH) at 8.9 $kg \cdot m^{-3}$ (15 $lb \cdot yd^{-3}$). After transplanting, all plants were placed on a full-sun nursery pad and received 1.3 cm (0.5 in) of overhead irrigation per day. On April 12 [28 C (84 F), 55% relative humidity, calm winds, clear skies], herbicides were applied over the top of all plants using a CO_2 backpack sprayer calibrated to deliver 468 $L \cdot ha^{-1}$ (50 $gal \cdot A^{-1}$) via a two nozzle handheld boom equipped with flat fan nozzles (8002, TeeJet Technologies, Wheaton, IL.). Herbicides evaluated included bentazon (Basagran® T/O, BASF, Corp., Research Triangle Park, NC) at 2.2 kg a i· ha^{-1} (2 lb ai·A^{-1}), clopyralid (Lontrel®, Corteva AgriSciences, Indianapolis, IN) at 1.1 kg ai· ha^{-1} (1 lb ai· A^{-1}), fluazifop-P-butyl (Fusilade® II, Syngenta Crop Protection, Greensboro, NC) at 0.84 kg ai· ha^{-1} (0.75 lb ai·A^{-1}), glufosinate (Finale®, BASF, Corp.) at 2.2 kg ai ha^{-1} (2 lb ai · A^{-1}), glyphosate (Ranger® Pro, Monsanto, St. Louis, MO) at 3.4 kg ai· ha^{-1} (3 lb ai A^{-1}), halosulfuron (SedgeHammer®, Gowan, Yuma, AZ) at 0.15 kg ai· ha^{-1} (0.13 lb ai· A^{-1}), imazaquin (Sceptor® T&O, Amvac Corp., Newport Beach, CA) at 1.1 kg ai· ha^{-1} (1 lb ai· A^{-1}), sethoxydim (Segment® II, BASF Corp.) at 1.6 kg ai· ha^{-1} (1.4 lb ai · A^{-1}), sulfentrazone (Dismiss®, FMC Corp., Philadelphia, PA) at 0.84 kg ai· ha^{-1} (0.75 lb ai· A^{-1}), and sulfosulfuron (Certainty®, Valent U.S.A. Corp., Walnut Creek, CA) at 0.21 kg ai· ha^{-1} (0.19 lb ai· A^{-1}). A nontreated control was also included for comparison. Herbicide rates evaluated generally represented 2 times the maximum labeled rate in order to confirm a high level of tolerance, which is needed in order to make recommendations to practitioners and represent a worst case scenario in which applicators are not properly calibrated. A nonionic surfactant (AirCover™, Winfield Solutions, St. Paul, MN) was added to bentazon, clopyralid, fluazifop-P-butyl, imazaquin, halosulfuron, sethoxydim, and sulfosulfuron at 0.25% v:v based on manufacturer label directions. All plant foliage was dry at the time of application and foliage remained dry until the following morning when irrigation was resumed (16 hr after treatment). Following treatment, all plants were grouped by species on the full-sun nursery pad described previously. At approximately 6 weeks after the first treatment, all treatments were reapplied following the same procedures on May 20 [31 C (89 F), 42% relative

humidity, winds 9.7 kl·h^{-1} (6 mph), clear skies). The experiment was repeated using the same methodology with plants in the second experimental run being transplanted on May 6, and receiving their first and second application on May 20 and July 1 [33 C (91 F), 52% relative humidity, winds 11 kl·h^{-1} (7 mph), partly cloudy skies).

The experiment was a completely randomized design with eight single pot replications per treatment for the first experimental run and six single pot replications per treatment for the second experimental run. Plants were grouped by species throughout the trial, and each species was treated as a separate experiment. Data collected included injury ratings taken visually on a 0 to 100 scale, where 0 indicated no injury and plants being similar in size and appearance to the non-treated control and 100 representing dead plants with no visible living tissue. Ratings were conducted at 2, 4, and 6 weeks after the first treatment (WAT1) and at 2, 4, and 8 weeks after the second treatment (WAT2). At 8 WAT2, all plants were cut at the soil line and shoot fresh weights were determined immediately after clipping using a portable balance. After fresh weight determination, all plants were placed into a forced air oven at 70 C (158 F) for 7 days, ensuring that a constant weight was reached, and then dry weights were recorded. Data were analyzed using a mixed model analysis of variance (ANOVA) in JMP® Pro software (ver. 14, SAS Institute, Cary, NC) with herbicide as a fixed effect and replication as a random effect. Prior to analysis, injury rating data were arcsine transformed as needed to meet the assumptions of ANOVA, but data were back-transformed for interpretation. Post hoc means comparisons were conducted using Tukey's honest significant differences (HSD) test ($P \leq 0.05$).

In Mobile, dwarf mondo grass (mondo grass) (*Ophiopogon japonicas* 'Nana') bibs were harvested from fully rooted 7.6 (3 in) pots. Bibs were selected for uniformity and then three bibs were transplanted into each 2.9 L (square gal) pots on April 11 using aged pine bark amended with dolomitic lime at 11.9 kg·m^{-3} (20 lb·yd^{-3}), controlled release fertilizer (18-6-8) (Nutricote®, Florikan, Sarasota, FL), and 0.9 kg·m^{-3} (1.5 lb·yd^{-3}) of a micronutrient package (MicroMax®, ICL Specialty Fertilizers, Dublin, OH). After potting, plants were placed under 50% shade and received 1.3 cm (0.5 in) irrigation per day. On May 30 [30 C (86 F), 60% relative humidity, calm winds), herbicide treatments were applied using a CO_2 backpack sprayer equipped with an 8004 flat-fan nozzle (TeeJet Technologies, Wheaton, IL) at an application volume of 496 l·ha^{-1} (53 gal·A^{-1}) to dry foliage. Herbicide rates were the same as those applied in Apopka but different products were used for clopyralid (Thistledown®, Monterey Lawn & Garden, Fresno, CA), glufosinate (Liberty®, Bayer Crop Science, Research Triangle Park, NC), glyphosate (Cornerstone® Plus, Winfield Solutions), and sethoxydim (Bonide Grass Beater®, Bonide Products, Oriskany, NY). Capsil® (Aquatrols, Paulsboro, NJ) was used as the nonionic surfactant and was added to the same herbicides as was done in Apopka. All foliage was dry at the time of application and remained dry for 24 hr until irrigation was resumed the following day. Treatments were reapplied on July 29 [33 C (91 F), 52% relative humidity, calm winds) using the same methodology. The experiment was repeated at this same time on a separate group of mondo grass using the same procedures with the repeat application on Oct. 3 [35 C (95 F), 47% relative humidity, calm winds, under shade). On Oct 31, the repeated study was moved to a passively ventilated greenhouse with 30% shade with a heater set point of 13 C (55 F).

The experiment in Mobile was a complete randomized block design with 10 single pot replications per treatment in both experimental runs, and a non-treated control group was included for comparison in both experimental runs. Data collected included injury ratings taken visually on a 0 to 100 scale in the same manner as was done in Apopka at 1, 4, and 8 WAT and 1, 4, 8 WAT2. Shoot dry weights were recorded at 8 WAT2 by clipping plants at the soil line and drying foliage in a forced air oven until a constant weight was achieved. In addition to injury ratings and shoot weights, bib counts per pot were recorded at trial initiation and at trial conclusion (8 WAT2). Data were analyzed as previously described.

Results and Discussion

Asiatic jasmine. At 2 WAT, the highest injury was observed in plants treated with glufosinate (41%), and was characterized by leaf necrosis, most notably occurring on newly emerging foliage (Table 1). At least some minor injury was noted in all treatments at this time, but only glufosinate was considered commercially unacceptable. By 4 WAT, plants treated with glufosinate had begun to recover, with lower injury ratings observed than at 2 WAT (41% decreasing to 27%). At this time, the highest injury was observed in plants treated with bentazon (39%) and clopyralid (31%), followed by sulfosulfuron (29%), which were rated as being similar to plants treated with glufosinate. Predominate injury symptoms were leaf distortion and leaf drop, leaf crinkling and general distortion, and stunted new growth for bentazon, clopyralid, and sulfosulfuron, respectively. Plants treated with glyphosate also had similar injury ratings, characterized by stunting and general chlorosis. This trend continued through 6 WAT, with bentazon resulting in the highest injury (52%) followed by clopyralid (37%), glufosinate (29%), glyphosate (33%) and sulfosulfuron (31%). Injury ratings in Asiatic jasmine treated with fluazifop-P-butyl, halosulfuron, imazaquin, or sethoxydim were not significantly different from non-treated plants after the first application. Similarly, while 19% injury was observed in plants treated with sulfentrazone at 2 WAT, plants recovered and only minor injury was noted at 4 and 6 WAT (injury ratings $\leq$ 3%). The same general trend was observed following the second application with greater injury observed in plants treated with bentazon (66% to 76%), clopyralid (36% to 50%), glufosinate (44% to 45%), glyphosate (34% to 37%), and sulfosulfuron (23% to 28%) compared to that seen after one application; however, plants treated with sulfosulfuron would have been considered acceptable (injury $\leq$ 30%). Similar to results observed with sulfosulfuron, only minor injury was observed in plants treated with imazaquin (injury $\leq$

Table 1. Tolerance of container-grown Asiatic jasmine 'Minima' and perennial peanut 'Golden Glory' to sequential applications of selected postemergence herbicides in Apopka, FL in 2019. Results are pooled over two experimental runs.

			First application[z]			Second application[y]			
	Rate[x]		2 WAT[w]	4 WAT	6 WAT	2 WAT2	4 WAT2	8 WAT2	shoot dry wt. (g)[v]
Herbicide	kg ai·ha^{-1}	lb ai·A^{-1}	Asiatic jasmine injury ratings (0 to 100)[u]						
bentazon	2.2	2.0	16 bc[t]	39 a	52 a	66 a	66 a	76 a	5.2 (-51) e
clopyralid	1.1	1.0	15 bcd	31 a	37 ab	36 bc	49 ab	50 b	7.4 (-30) bcd
fluazifop-P-butyl	0.84	0.75	1 e	1 c	0 c	0 e	0 e	0 e	10.0 (-6) a
glufosinate	2.2	2.0	41 a	27 a	29 b	44 b	42 bc	45 bc	5.2 (-51) e
glyphosate	3.4	3.0	10 bcde	24 ab	33 b	34 bc	37 bc	36 bc	6.3 (-41) de
halosulfuron	0.15	0.13	2 cde	9 bc	0 c	0 e	0 e	0 e	7.8 (-26) bcd
imazaquin	1.1	1.0	4 cde	4 c	5 c	19 cd	17 de	18 d	9.3 (-12) ab
sethoxydim	1.6	1.4	1 de	0 c	0 c	0 e	0 e	0 e	10.7 (+1) a
sulfentrazone	0.84	0.75	19 b	3 c	0 c	2 de	4 e	0 e	8.7 (-18) abc
sulfosulfuron	0.21	0.19	2 cde	29 a	31 b	23 c	25 cd	28 cd	6.8 (-36) cde
Control	—	—	0 e	0 c	0 c	0 e	0 e	0 e	10.6 (0) a
			Perennial Peanut injury ratings (0 to 100)						
bentazon	2.2	2.0	7 d	4 d	0 d	0 d	0 d	2 c	32.5 (-12) ab
clopyralid	1.1	1.0	32 bc	71 b	100 a	100 a	100 a	100 a	0.0 (-100) d
fluazifop-P-butyl	0.84	0.75	6 d	2 d	0 d	8 c	9 c	0 c	33.0 (-10) a
glufosinate	2.2	2.0	62 a	71 b	74 b	100 a	100 a	100 a	0.0 (-100) d
glyphosate	3.4	3.0	53 ab	96 a	96 a	100 a	100 a	100 a	0.0 (-100) d
halosulfuron	0.15	0.13	9 d	3 d	0 d	0 d	0 d	0 c	24.6 (-33) bc
imazaquin	1.1	1.0	11 cd	29 c	32 c	37 b	45 b	51 b	19.8 (-46) c
sethoxydim	1.6	1.4	1 d	1 d	0 d	0 d	0 d	0 c	33.3 (-10) a
sulfentrazone	0.84	0.75	15 cd	5 d	1 d	1 d	0 d	0 c	30.5 (-17) ab
sulfosulfuron	0.21	0.19	20 cd	64 b	91 a	98 a	99 a	99 a	0.3 (-99) d
Control	—	—	0 d	0 d	0 d	0 d	0 d	0 c	36.8 (0) a

[z]The first application was applied on April 11 and May 20 for experimental runs 1 and 2 respectively, and results are averaged across the two runs.

[y]The second application was applied on May 20 and July 1 for experimental runs 1 and 2, respectively, and results are averaged across the two runs.

[x]Rate is expressed in amount of active ingredient applied on a per hectare or per acre basis. A non-ionic surfactant (AirCover®, Winfield Solutions, St. Paul, MN) was added to bentazon, clopyralid, fluazifop-P-butyl, halosulfuron, imazaquin, sethoxydim, and sulfosulfuron at 0.25% v:v based on manufacturer label directions. All rates are approximately 2 times the maximum labeled rate.

[w]WAT = weeks after treatment.

[v]Shows shoot dry weights collected at 8 weeks after the second application. Percent increase (+) or decrease (-) in growth relative to the non-treated control is presented parenthetically.

[u]Injury ratings were taken on a 0 to 100 scale, 0 = no injury, 30 = maximum acceptable injury, and 100 = dead plant and no visible living tissue.

[t]Means within a column and species followed by the same letter are not significantly different according to Tukey's HSD test ($P \leq 0.05$).

19%), characterized by minor stunting, and plants were considered acceptable. Minimal to no injury was observed in plants treated with fluazifop-P-butyl, halosulfuron, sethoxydim, or sulfentrazone following the second application.

Although treatments including fluazifop-P-butyl, halosulfuron, imazaquin, sethoxydim, and sulfentrazone caused no significant injury following two applications, shoot weight data revealed halosulfuron reduced Asiatic jasmine shot weight by 26%, a reduction relative to non-treated plants (Table 1). However, fluazifop-P-butyl, imazaquin, sethoxydim, and sulfentrazone caused no reduction in shoot weight. It is not surprising that minimal injury and no growth reductions were observed with fluazifop, imazaquin, or sethoxydim as all are currently labeled for over the top use in Asiatic jasmine, either in container production, in the landscape, or both. In contrast, sulfosulfuron is also labeled for over the top application as Certainty® (Anonymous 2016), but injury ratings up to 31% were observed as well as a 36% reduction in growth. Higher than expected injury and subsequent stunting is likely due to the higher than labeled rate (2×) as well as the plants being evaluated in containers as opposed to established plants on the landscape, which are permitted for treatment on the label.

Neither halosulfuron nor sulfentrazone are labeled for over the top use on Asiatic jasmine, but were only minimally injurious based on visual inspections when applied twice at 2 times the label rate. While halosulfuron caused a growth reduction in comparison with non-treated plants, sulfentrazone did not. As growth reductions occurred with halosulfuron, it would probably not be option on newly planted Asiatic jasmine, but could potentially be utilized on mature and fully established Asiatic jasmine when growth reductions would not be as problematic. Sulfentrazone cause some minor injury, characterized by chlorosis and some minor leaf drop ($\leq$ 19%), especially following the first application when plants were newly transplanted. However, as no growth reductions occurred and injury was minimal, sulfentrazone could potentially be an option for sedge and broadleaf weed control. All other herbicide treatments resulted in growth reductions of 30% to over 50% (bentazon, glufosinate, glyphosate) or caused significant foliar injury and stunting

(clopyralid) and would not be recommended for use on newly planted Asiatic jasmine.

While there are no reports (to our knowledge) on Asiatic jasmine tolerance to clopyralid or bentazon, glyphosate has been tested as an over the top treatment to Asiatic jasmine and is used by some landscape maintenance companies or golf courses for weed control in Asiatic jasmine beds. Hoogmoed et al. (2012) reported no injury to container-grown Asiatic jasmine following applications of glyphosate at up to a 2.2 kg ai·ha^{-1} rate (2 lb ai·A^{-1}) following June or September applications, but observed significant injury following a February application, noting plants were most actively growing and contained a new flush of growth prior to the February treatment. The authors also reported injury following multiple glyphosate applications. In contrast to results by Hoogmoed et al., injury was observed in our study after just one application applied in April or May, but plants were growing vigorously at the time of treatment, similar to when Hoogmoed et al. (2012) reported injury after a February application. Our results are also in agreement with Hoogmoed et al. (2012) in that we also observed injury after two applications that ranged from 34 to 37%. Based on our results and previous reports, Asiatic jasmine does have a relatively high tolerance to glyphosate, probably due to limited foliar absorption. However, while some tolerance has been observed, injury and growth reductions would also be likely depending upon the stage of growth. Asiatic jasmine susceptibility to injury may also increase as the number of applications increase (Hoogmoed et al. 2012). Based on previous reports and our results, glyphosate would not be recommended for use is Asiatic jasmine, especially in high maintenance or highly visible landscaped areas.

Perennial peanut. Whereas most herbicides tended to cause only moderate injury to Asiatic jasmine, treatments were either highly injurious or cause no to very minimal injury to perennial peanut. Perennial peanut treated with bentazon, halosulfuron, and sethoxydim, and sulfentrazone all had injury ratings similar to the non-treated control on all evaluation dates (Table 1). Fluazifop was also only minimally injurious, with injury ratings $\leq$ 6% on all evaluation dates, characterized by minor chlorosis on new foliage. In contrast, clopyralid, glufosinate, glyphosate, and sulfosulfuron were highly injurious, with most plants having injury ratings of 100% after 4 WAT. Injury with these herbicides was initially severe chlorosis and necrosis, progressing to complete plant death in most instances. Imazaquin application also caused significant injury, which was distorted and stunted new growth, characteristic of acetolactate synthase inhibiting herbicides (Whitcomb 1999). Injury ratings were reflected in shoot weight data, with applications of bentazon, fluazifop, and sethoxydim, and sulfentrazone resulting in no significant reductions in growth relative to the non-treated control. While minimal injury was observed with halosulfuron, shoot weights were reduced by 33% in comparison with plants that were not treated. Imazaquin did not result in plant death, but significant growth reductions were noted (46% reduction in relation to non-treated). All other treatments resulted in $\geq$ 99% reduction in growth and few plants lived throughout the duration of the experiment following applications with clopyralid, glufosinate, glyphosate, or sulfosulfuron.

There are currently no herbicides (pre- or postemergence) labeled for use in perennial peanut in residential or commercial landscape sites. Thus, recommendations for weed control are often derived from products either used for weed control in perennial peanut in pastures such as imazapic, hexazinone, or 2,4-D, or registered for use in peanut grown as a crop (*Arachis hypogaea* L.), such as bentazon, or gramicides such as fluazifop or clethodim (Rouse et al. 2004). Results from these studies confirm that bentazon and fluazifop would not cause injury newly planted perennial peanut, as well as sethoxydim and sulfentrazone, which has not previously been recommended for grass or sedge weed control. Due to the growth habit of perennial peanut, halosulfuron caused only minor visible stunting, but reduced growth by 34%. While stunting was not visually evident in containers, it is possible the stunting may be more observable and unacceptable in the landscape. As stunting was the only injury that occurred following halosulfuron application, it could potentially be used in established perennial peanut where growth reductions were acceptable. Further testing is needed as it is unknown how different cultivars and species of perennial peanut would tolerate these treatments.

It is clear that clopyralid, glufosinate, glyphosate, or sulfosulfuron would not be recommended for use in perennial peanut. A high degree of injury was expected with clopyralid as it is highly active on leguminous plants and labels typically state not to apply in close proximity to desirable legumes (DiTomaso et al. 1999). Glufosinate and glyphosate are both non-selective herbicides, and although glyphosate has been recommended and labeled for use in perennial peanut in pastures (Sellers and Ferrell 2005), applications are usually limited to the dormant season and a much higher degree of injury is acceptable in pastures compared with landscapes. Further, during periods of active growth, significant injury has been reported to perennial peanut with glyphosate (Valencia et al. 1999). Sulfosulfuron would not be an option for weed control in perennial peanut, but it is currently labeled for use in all common warm-season turfgrass species in Florida (Anonymous 2016). Although perennial peanut is a desirable groundcover, some cultivars or species may spread outside its intended space into turfgrass areas, becoming a weed issue in some cases (Pitty n.d.). In these situations, sulfosulfuron could be used for selective control, and would be a more flexible option than clopyralid as it is labeled for use in residential lawns in contrast to clopyralid (Anonymous 2019a).

Dwarf mondo grass. Following the first application (1 WAT), the highest injury ratings were observed in plants treated with glufosinate (89% to 100%) and glyphosate (65% to 100%), followed by sulfentrazone (47% to 75%) (Table 2). Injury observed included leaf necrosis, severe chlorosis and necrosis, and leaf spotting, along with necrotic leaf margins in plants treated with glufosinate, glyphosate, and sulfentrazone, respectively. Less injury was observed in plants treated with bentazon, although

Table 2. Tolerance of container-grown dwarf mondo grass (*Ophiopogon japonicum* 'Nana') to sequential application of selected postemergence herbicides in Mobile, AL. Results are pooled over two experimental runs.

			First application[z]			Second application[y]				
	Rate[x]		1 WAT[w]	4 WAT	8 WAT	1 WAT2	4 WAT2	8 WAT2		
Herbicide	kg ai·ha^{-1}	lb ai·A^{-1}	Injury ratings (0 to 100)[t]						shoot dry wt. (g)[v]	bibb count[u]
bentazon	2.2	2.0	30 d[s]	32 c	13 c	48 b	45 b	25 c	4.4 (-29) c	19.2 (+4) cd
clopyralid	1.1	1.0	0 e	0 d	0 d	0 e	0 c	0 d	4.7 (-24) bc	17.2 (-7) de
fluazifop-P-butyl	0.84	0.75	0 e	0 d	0 d	0 e	0 c	0 d	5.6 (-10) ab	20.7 (+12) bcd
glufosinate	2.2	2.0	89 a	100 a	99 a	100 a	100 a	97 a	0.5 (-92) f	0.6 (-97) f
glyphosate	3.4	3.0	65 b	98 a	100 a	100 a	100 a	100 a	0.6 (-90) f	0.2 (-99) f
halosulfuron	0.15	0.13	0 e	0 d	17 c	27 c	43 b	47 b	2.8 (-55) de	25.0 (+35) ab
imazaquin	1.1	1.0	0 e	0 d	7 cd	13 d	11 c	10 d	3.3 (-47) d	23.7 (+28) abc
sethoxydim	1.6	1.4	0 e	0 d	0 d	0 e	0 c	0 d	5.6 (-10) ab	19.2 (+4) cd
sulfentrazone	0.84	0.75	47 c	75 b	62 b	91 a	98 a	97 a	2.4 (-61) e	14.5 (-22) e
sulfosulfuron	0.21	0.19	18 d	21 c	15 c	21 cd	44 b	31 c	3.2 (-48) de	27.8 (+50) a
Control	—	—	0 e	0 d	0 d	0 e	0 c	0 d	6.2 (0) a	18.5 (0) de

[z]The first application was applied on May 30 and July 29 for experimental runs 1 and 2 respectively, and the results are averaged over the two runs.

[y]The second application was applied on July 29 and Oct. 3 for experimental runs 1 and 2, respectively, and the results are averaged over the two runs.

[x]Rate is expressed in amount of active ingredient applied on a per hectare or per acre basis. A non-ionic surfactant (Capsil®, Aquatrols, Paulsboro, NJ) was added to bentazon, clopyralid, fluazifop-P-butyl, halosulfuron, imazaquin, sethoxydim, and sulfosulfuron at 0.25% v:v based on manufacturer label directions. All rates are approximately 2 times the maximum labeled rate.

[w]WAT = weeks after treatment.

[v]Shows shoot dry weights collected at 8 weeks after the second application. Percent increase (+) or decrease (-) in growth relative to the non-treated control is presented parenthetically.

[u]Injury ratings were taken on a 0 to 100 scale, 0 = no injury, 30 = maximum acceptable injury, and 100 = dead plant and no visible living tissue.

[t]Bibb counts show mean number of living bibbs per pot at 8 weeks after the second application. Percent increase (+) or decrease (-) in growth relative to the non-treated control is presented parenthetically.

[s]Means within a column followed by the same letter are not significantly different according to Tukey's HSD test ($P \leq 0.05$).

injury ratings (chlorosis) were above or equal to our commercially accepted level of 30%. Recovery was noted at 8 WAT as injury decreased from 32% to 13%. Clopyralid, fluazifop-P-butyl, imazaquin, and sethoxydim caused no significant injury following the first application. Similarly, no injury was observed in plants treated with halosulfuron except at 8 WAT when injury (general chlorosis) was 17%, still within acceptable limits. Minor injury symptoms of stunting and chlorosis ($\leq$ 21%) was observed in plants treated with sulfosulfuron on all evaluation dates, but plants were considered commercially acceptable.

Following the second application, high mortality was observed in plants treated with glufosinate, glyphosate, and sulfentrazone, with injury ratings exceeding 90% on all evaluation dates. Glyphosate and glufosinate resulted in an over 90% reduction in shoot dry weight. In contrast, sulfentrazone reduced dry weights by just 60%, despite very high injury ratings similar to those of plants treated with glyphosate or glufosinate. This was primarily a result of less complete necrosis and death in the sulfentrazone treatment compared with glufosinate and glyphosate, although foliage was very necrotic, chlorotic, and stunted. Although not as injurious as glyphosate, glufosinate or sulfentrazone, significant injury was also observed in plants treated with bentazon, halosulfuron, and sulfosulfuron, with ratings ranging from ~20% to ~45% for plants treated with any of these three herbicides. Significant growth reductions were also noted as dwarf mondo grass shoot weights were reduced by 29%, 55%, and 48% when treated with bentazon, halosulfuron, or sulfosulfuron, respectively. As only minimal injury was noted in dwarf mondo grass following the first application with halosulfuron or sulfosulfuron, data suggest dwarf mondo grass would likely be tolerant to a single application at label rates, but follow up applications would need to be timed much further apart than 8 weeks to avoid injury. Similar to results following the first application, no significant injury was observed in plants treated with clopyralid, fluazifop-P-butyl, or sethoxydim. Similar to our findings, Rice et al. (1985) reported no injury to mondo grass following applications of sethoxydim or fluazifop-P-butyl at rates up to 2.24 kg ai· ha^{-1} (2 lb ai· A^{-1}). While sethoxydim is registered for use on mondo grass, fluazifop-P-butyl labels indicate that up to 20% injury may be possible and only directed applications are recommended (Anonymous 2014; 2017).

While fluazifop-P-butyl and sethoxydim caused no reduction in shoot growth, clopyralid reduced shoot dry weights by 24%. Similarly, only minor injury was noted with ratings taken visually in plants treated with imazaquin, but shoot weight data revealed a growth reduction of 47%, a similar reduction to plants that had been treated with more injurious herbicides, such as halosulfuron or sulfosulfuron. Although shoot weight data revealed a significant growth reduction, plants were considered marketable and only minor stunting could be observed visually. Imazaquin and sulfosulfuron are labeled for use in mondo grass in landscapes (Anonymous 2016, 2019b), but similar to results with sulfosulfuron applied to Asiatic jasmine, imazaquin and sulfosulfuron were both injurious, at least from a growth perspective, when applied to newly transplanted dwarf mondo grass in containers. Similar to growth reductions observed with halosulfuron in perennial

Table 3. Current product labelling and observed injury to Asiatic jasmine (*Trachelospermum asiaticum*), dwarf mondo grass (*Ophiopogon japonicus* 'Nana'), and perennial peanut (*Arachis pintoi* 'Golden Glory') following application with selected postemergence herbicides.

		Asiatic jasmine	Dwarf mondo grass	Perennial peanut
Herbicide	**Trade name**	**Tolerance summary[z]**		
bentazon	Basagran® T/O	Not labeled. Significant injury occurred after one application and increased after the second. Growth was reduced by 51%.	Not labeled. Moderate injury after one application and increased after the second. Growth was reduced by 29%.	Not labeled. No significant injury and no reductions in growth occurred following two applications.
clopyralid	Lontrel®	Not labeled. Significant injury occurred after one application and increased after the second. Growth was reduced by 30%	Not labeled. No injury after two applications. Growth was reduced by 24%.	Not labeled. Severe injury and death occurred after one application.
fluazifop-P-butyl	Fusilade® II	Labeled. No injury or growth reduction occurred.	Labeled as a directed application only. No injury or growth reduction occurred.	Not labeled. No significant injury or growth reduction occurred.
glufosinate	Finale®	Not labeled. Significant injury occurred after one application and increased after the second. Growth was reduced.	Not labeled. Severe injury and death occurred after one application.	Not labeled. Severe injury and death occurred after one application.
glyphosate	Ranger Pro®	Not labeled. Moderate injury occurred after two applications. Growth was reduced by 41%.	Not labeled. Severe injury and death occurred after one application.	Not labeled. Severe injury and death occurred after one application.
halosulfuron	SedgeHammer®[y]	Not labeled. No significant injury occurred after two applications. Growth was reduced by 26%.	Not labeled. Minor injury after one application but unacceptable (≥30%) after two applications. Growth was reduced by 55%.	Not labeled. No significant injury occurred but growth was reduced by 33%.
imazaquin	Scepter® T/O	Labeled. Only minor injury was observed but was acceptable (≤19%). No growth reduction occurred.	Labeled. Only minor to moderate injury was observed but growth was reduced by 47%.	Not labeled. Moderate injury occurred after one application and increased after the second application. Growth was reduced by 46%.
sethoxydim	Segment® II	Labeled. No injury or growth reductions occurred.	Labeled. No injury or growth reduction occurred.	Not labeled. No injury or growth reduction occurred.
sulfentrazone	Dismiss®	Not labeled. Only minor injury was observed but full recovery was noted. No growth reduction occurred.	Not labeled. Severe injury occurred after one application and increased after the second application. Growth was reduced by 61%.	Not labeled. Only minor injury was observed but full recovery was noted. No growth reduction occurred.
sulfosulfuron	Certainty®	Labeled. Unacceptable (≥30%) injury was observed after one application. Growth was reduced by 36%.	Labeled. Only minor injury was observed after one application but was unacceptable after the second application. Growth was reduced by 48%.	Not labeled. Severe injury and death occurred after one application.

[z]Products listed as labeled or not labeled refers to over-the-top applications in landscape settings. Injury was considered unacceptable after reaching or exceeding 30% based on phytotoxicity ratings taken visually. Growth assessments were made based on shoot dry weights collected at 8 weeks following the second application. All products were applied twice at twice their highest recommended label rate.

peanut that appeared marketable visually in containers, growth reductions may be more evident or problematic in landscape settings, especially during plant establishment.

All herbicide-treated plants either had a similar or greater number of bibbs than the non-treated control at 8 WAT2, with the exception of glyphosate and glufosinate, which reduced bibb counts by over 90%. Interestingly, while treatments including halosulfuron, imazaquin, and sulfosulfuron increased bibb counts by 28% to 50%, the size of each remaining bibb was much smaller than the non-treated control based on the ratio of shoot dry weight to bibb count. The reason for increased bibb production following treatment with sulfonylurea herbicides (halosulfuron and sulfosulfuron) or an acetolactate synthase (ALS) inhibitor (imazaquin) is unclear as both classes of herbicides typically cause an immediate inhibition of growth on susceptible species following application (Brown 1990; Zhou et al. 2007). As only moderate injury was observed, increased bibb counts may be a result of regrowth from rhizomes following sequential applications that caused foliar injury, or could be a stress response, but more research would be needed to elucidate the herbicidal mechanism causing increased bibb counts.

Results from these experiments show that several postemergence herbicides not currently labeled for use in Asiatic jasmine, dwarf mondo grass, or perennial peanut could be potential options for weed management in these groundcovers (Table 3). Of the herbicides not currently labeled for over-the-top applications to Asiatic jasmine, halosulfuron and sulfentrazone were found to cause no significant injury, although halosulfuron did decrease growth by 26%. These herbicides could be potentially used for sedge control in established Asiatic jasmine, and were generally less injurious than sulfosulfuron, which is currently labeled for use in established Asiatic jasmine beds in landscapes.

Dwarf mondo grass showed a high level of tolerance to clopyralid and fluazifop-P-butyl, neither of which are

currently labeled for over-the-top applications, although a growth reduction was observed with clopyralid. In established mondo grass beds, clopyralid could be an option for broadleaf weed control, which is needed as most currently labeled products such as imazaquin, sethoxydim, and sulfosulfuron are often more efficacious on sedge species or grasses as opposed to broadleaf weeds.

There are currently no herbicides registered for use in perennial peanut growing in landscape areas, but data showed that bentazon, fluazifop-P-butyl, sethoxydim, and sulfentrazone exhibited no significant injury following two applications at two times the label rate. Additionally, halosulfuron also caused only minor injury but did decrease growth, thus it may only be an option following full establishment.

Several herbicides caused injury to species listed as approved for over-the-top application on herbicide product labels. In Asiatic jasmine, unacceptable injury was observed with sulfosulfuron, which caused injury ratings of 31% at 6 WAT and a growth decrease of 36%. Similarly, imazaquin reduced growth of mondo grass by 47%, and sulfosulfuron resulted in injury ratings of 44% at 4 WAT2 and a growth reduction of 48%. It should be noted that these trials were conducted on newly transplanted liners in containers, and a rate twice the use rate was selected as the dose to represent a worst-case scenario. In contrast, these products are registered for use in landscapes, and applications to container-grown ornamentals are not allowed. Thus, data presented here should not be used as an indication these products are injurious on these groundcovers if label directions are followed, but it does illustrate the need for proper calibration and the need to delay applications until the groundcovers are fully established.

Overall, there would be several postemergence herbicide options for control of sedge and grassy weeds in each of these three groundcovers. Several options such as halosulfuron, sulfosulfuron, imazaquin, and sulfentrazone could also control certain broadleaf weeds, but the spectrum of control would be lacking. By far, selective broadleaf weed control would be the most challenging in these beds, thus practitioners should still focus on use of preemergence herbicides, which are generally not injurious to these species and could be used to control a broad range of broadleaf weeds. As herbicides may cause more or less injury to different cultivars of the same species, further testing would be needed before making any broad recommendations for use of these herbicides in different cultivars of Asiatic jasmine or mondo grass, or other species or cultivars of perennial peanut not tested here.

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