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Ornamental plant safety and weed control with indaziflam

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Research Article

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Nomenclature:
Indaziflam; Giant foxtail, *Setaria faberi* Herrm.; hairy bittercress, *Cardamine hirsute* L.; Large crabgrass, *Digitaria sanguinalis* (L.) Scop.; Andorra Compacta creeping juniper, *Juniperus horizontalis* Moench; Black Dragon Japanese cedar, *Cryptomeria japonica* D. Don; Blue Rug creeping juniper, *Juniperus horizontalis* Moench; Blue Pfitzer Chinese pyramid juniper, *Juniperus chinensis* L.; Chinese pyramid juniper, *Juniperus chinensis* L.; Common juniper, *Juniperus communis* L.; Creeping woodsorrel, *Oxalis corniculate* L.; Eastern hemlock, *Tsuga canadensis* (L.) Carrière; eastern white pine, *Pinus strobus* L.; Norway spruce, *Picea abies* (L.) H. Karst.

Keywords:
Container-grown ornamentals; crop safety; indaziflam; postemergence; preemergence; weed management

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Abstract

Indaziflam was evaluated in Connecticut and Tennessee for weed control and safety of container-grown ornamental plants. Indaziflam was applied at 49, 98, or 196 g ha^{-1} to container-grown ornamental plants on an outdoor gravel pad and also applied preemergence or early postemergence to weeds in a greenhouse. Ornamental plants were treated twice annually in 2020 and 2021 in Connecticut, and in 2019 and 2020 in Tennessee, with approximately 6 wk between applications. Chinese pyramid juniper, common juniper, eastern hemlock, eastern white pine, and Norway spruce in Connecticut, and 'Andorra Compacta' creeping juniper and 'Black Dragon' Japanese cedar, 'Blue Rug' creeping juniper, and 'Blue Pfitzer' Chinese pyramid juniper in Tennessee were not injured with indaziflam regardless of the rate applied. Preemergence application of indaziflam reduced densities of creeping woodsorrel, hairy bittercress, giant foxtail, and large crabgrass by 72% to 100%, depending on the indaziflam rate applied, by 28 d after treatment (DAT). When applied early postemergence, indaziflam provided 97% to 99% control of creeping woodsorrel (1- to 2-leaf), fringed willowherb (4- to 6-leaf), hairy bittercress (cotyledon to 1-leaf), and mouse-ear chickweed (2- to 4-leaf) by 28 DAT. Compared with a nontreated control, the total fresh shoot biomass reduction was 86% to 100% and 78% to 100% following preemergence or postemergence applications. Indaziflam offers a new site of action with excellent safety and weed control in the tested ornamental plants.

Introduction

Weed competition for resources (light, water, space, or nutrients) results in reduced growth and development of ornamental plants (Aulakh 2023; Aulakh et al. 2024; Berchielli-Robertson et al. 1990; Fretz 1972; Neal 1999; Walker and Williams 1989). Competition is more intense in a container production system because of limited resource availability due to a small planting media volume. Ornamental plant growers rely on preemergence herbicides and hand weeding for weed management (Altland et al. 2004). Manual weed control is costly because of increasing labor expenses. Annually, nurserymen spend US$500 to $4,000 yearly on hand weeding (Mathers 2003). Hand weeding 1,000 3-L pots over 4 mo costs about $1,370 (Darden and Neal 1999). In aggregate, economic losses (weed management costs and loss of crop productivity) from weed competition may cost as much as $17,300 per ha (Case et al. 2005).

Preemergence herbicides offer broad-spectrum, economical, and long-duration weed control. Recently, indaziflam (Marengo®; Bayer CropScience LP, Cary, NC) has been registered for control of broadleaf weeds, grasses, and sedges in container- and field-grown ornamental, conifer, and Christmas tree plantations; on nonbearing fruit and nut trees, on greenhouse floors, and in ornamental plant production facilities (shadehouses, hoophouses, lathhouses) and hardscapes (Anonymous 2024). Indaziflam, a Group 29 herbicide (as categorized by the Weed Science Society of America), is a cellulose biosynthesis inhibitor herbicide (Ahrens 2015; Brabham et al. 2014; Myers et al. 2009; Tateno et al. 2016). It controls sensitive weeds by inhibiting crystalline cellulose deposition in the cell wall, thereby affecting cell wall formation, cell division, and cell elongation in the growing meristematic regions of emerging seeds (Anonymous 2024). Indaziflam offers preemergence and early postemergence activity on grass and broadleaf weeds.

Several previous studies have reported that indaziflam applied preemergence or early postemergence has been highly effective in controlling multiple broadleaf and grass weed species (Aulakh 2020; Besançon et al. 2023; Brosnan et al. 2011, 2012; Jhala et al. 2013; Marble et al. 2013, 2016; McCullough et al. 2013; Perry et al. 2011; Ramanathan et al. 2023; Smith et al. 2022). In some of these previous studies, the efficacy of indaziflam for weed control is equal to or better than that of other herbicides such as dithiopyr, prodiamine, and oxadiazon. Besançon and Bouchelle (2023) found fall applications of indaziflam at 146 g ha^{-1} to be more effective than

Table 1. Ornamental plant species and materials used in crop safety experiments.

Site	Ornamental species	Plug/liner size	Container size	Transplanting date	First indaziflam application	Second indaziflam application	Application volume
			L				L ha^{-1}
CT	Chinese pyramid juniper (*Juniperus chinensis* L.)	(6 × 6 cm), 12 to 18 cm	5.6	May 8, 2020, May 26, 2021	June 1, 2020, June 18, 2021	July 9, 2020, July 28, 2021	187
	common juniper (*Juniperus x media*)	(6 × 6 cm), 10 to 15 cm	5.6	May 8, 2020, May 26, 2021	June 1, 2020, June 18, 2021	July 9, 2020, July 28, 2021	187
	eastern hemlock (*Tsuga canadensis* (L.) *Carrière*)	(2+1), 20 to 25 cm	5.6	May 8, 2020, May 26, 2021	June 1, 2020, June 18, 2021	July 9, 2020, July 28, 2021	187
	eastern white pine (*Pinus strobus* L.)	(3+1), 25 to 30 cm	5.6	May 8, 2020, May 26, 2021	June 1, 2020, June 18, 2021	July 9, 2020, July 28, 2021	187
	Norway spruce (*Picea abies* (L.) H. Karst.)	(2+2), 35 to 45 cm	5.6	May 8, 2020, May 26, 2021	June 1, 2020, June 18, 2021	July 9, 2020, July 28, 2021	187
TN	'Andorra Compacta' creeping juniper (*Juniperus horizontalis*)	(10 × 10 cm), 20 to 22 cm	3.7	June 7, 2019	June 11, 2019	July 24, 2019	281
	'Black Dragon' Japanese cedar (*Cryptomeria japonica* (L.f.) D.Don)	32-cell flat, 25 cm	3.7	June 7, 2019	June 11, 2019	July 24/2019	281
	'Blue Rug' creeping juniper (*Juniperus horizontalis* Moench)	60-cell flat, 8 to 10 cm	2.3	August 4, 2020	August 6, 2020	September 18, 2020	281
	'Blue Pfitzer' Chinese juniper (*Juniperus chinensis* L.)	60-cell flat, 15 to 20 cm	2.3	August 4, 2020	August 6, 2020	September 18, 2020	281

spring applications in controlling horseweed and large crabgrass when applied to northern highbush blueberry (*Vaccinium corymbosum* L.). Similarly, Aulakh (2020) reported >80% of season-long control for giant foxtail, horseweed, large crabgrass, and redroot pigweed when indaziflam was applied preemergence at 40 g ha^{-1} to Canaan fir (*Abies balsamea* (L.) Mill. var. *balsamea*) before bud-break.

Indaziflam has been evaluated for crop tolerance in many specialty crops, including Christmas trees, nonbearing fruit and nut trees, tropical ornamental plants, and turf (Aulakh 2020; Basinger et al. 2019; Boyd and Steed 2021; Grey et al. 2016, 2018; Hurdle et al. 2020; Jhala et al. 2013; McCullough et al. 2013). Crop tolerance to indaziflam varies by plant species and the indaziflam rate applied. For instance, azalea (*Rhododendron* spp.), rose (*Rosa* spp.), and yew (*Taxus* media) were tolerant to indaziflam rates up to 200 g ha^{-1} (Palmer 2022). Whereas candytuft (*Iberis* spp.), daylily (*Hemerocallis* spp.), hosta (*Hosta* spp.), hydrangea (*Hydrangea* spp.), phlox (*Phlox paniculata* L.), purple coneflower (*Echinacea purpurea* (L.) Moench), salvia (*Salvia sylvestris* (L.)), and zinnia (*Zinnia* spp.) plants were found to be sensitive to indaziflam (Palmer 2022).

Indaziflam can be applied as a directed spray or over the top to established field- or container-grown ornamentals (Anonymous 2024). The maximum single application rate varies from 41 to 84 g ha^{-1} and a maximum seasonal application rate is 101 g ha^{-1}. Indaziflam provides an extended period of weed control due to a half-life that is greater than 150 d, allowing for season-long weed control (González Delgado et al. 2015, 2016). To date, limited information on indaziflam safety to container-grown ornamental plants is available. Therefore, the objectives of this research were to evaluate the safety of indaziflam on various container-grown ornamentals and its effectiveness in preemergence or early postemergence weed control.

Materials and Methods

Crop Safety Experiments

Indaziflam was evaluated for safety of various container-grown ornamental plants. Experiments were conducted at the Valley Laboratory of the Connecticut Agricultural Experiment Station in Windsor, CT, in 2020 and 2021; and at the Tennessee State University Otis L. Floyd Nursery Research Center in McMinnville, TN, in 2019 and 2020. Details on ornamental plant species and materials used at both locations are given in Table 1.

In Connecticut, ornamental plants were transplanted into 5.6-L plastic containers (C600; Nursery Supplies Inc., Chambersburg, PA) filled with pine bark and composted woodchips (1:1) mixture. The container substrate for experiments in Connecticut was amended with 2.8 kg m^{-3} 20N-4.3P-8.3K controlled-release fertilizer (Harrells Profertilizer; Harrells LLC, Lakeland, FL), 0.1 kg m^{-3} booster micronutrients (Harrells), and 1.7 kg m^{-3} dolomitic limestone (Plant Products LLC, Findley, OH). In Tennessee, ornamental plants were transplanted into 3.7-L (C400) or 2.3 L (C300S) containers (Nursery Supplies) filled with pine bark (Morton's Horticultural Products, McMinnville, TN). For experiments in Tennessee, the pine bark substrate was amended with 2.6 kg m^{-3} 14N-6.1P-11.6K controlled-release fertilizer (Florikan Type 100; Florikan LLC, Sarasota, FL), 0.5 kg m^{-3} micronutrient granules (Micromax; Everris, Dublin, OH), and 1.7 kg m^{-3}dolomitic limestone (Plant Products). Containers were kept on an outdoor gravel pad at both locations. Experiments were repeated, and the ornamental plants were transplanted into the same-sized containers and container substrates as described on May 26, 2021, in Connecticut (Table 1). In Tennessee experiments, different plant species were evaluated in 2020 (Table 1). The experiment was arranged in a completely randomized design with 12 replications per treatment.

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In Connecticut experiments, indaziflam was applied to the new growth approximately 3 wk after transplanting (Table 1). In Tennessee, indaziflam was applied within 4 d after transplanting (Table 1). Indaziflam was applied at 49, 98, or 196 g ha^{-1} with a compressed CO_2 research plot sprayer calibrated to deliver a spray volume of 187 or 280 L ha^{-1} through a single flat-fan AI8002VS or 8003VS spray nozzle (TeeJet Technologies; Glendale Heights, IL) in Connecticut and Tennessee, respectively, at 207 kPa and 1.3 m s^{-1}. Each indaziflam treatment was applied to 12 plants per ornamental plant species. A second application occurred approximately 6 wk after the initial application. The maximum recommended rate for indaziflam in a single broadcast application is 82 g ha^{-1}. The maximum seasonal application rate is 101 g ha^{-1}. The rate of 98 or 196 g ha^{-1} used in this study was above the maximum labeled rates for a single application. All ornamental plant species received 1.25 cm of overhead irrigation approximately 2 h after treatment application and daily thereafter.

Weed Efficacy Experiments

Indaziflam was evaluated for preemergence or early postemergence weed control at the Valley Laboratory of the Connecticut Agricultural Experiment Station in Windsor, CT. Greenhouse experiments were initiated on June 8, 2022, and were repeated on May 29, 2023. For each preemergence or early postemergence experiment run, 96 containers (9 cm diameter, SVD350; T.O. Plastics) were filled with the Premium All Purpose planting media (Pro-Mix, Quakertown, PA). Pro-Mix Premium All Purpose contains Canadian sphagnum peat moss (80% to 90%), peat humus, perlite, limestone, and mycorrhizae PTB297 technology. Containers were watered using 1.25-cm overhead mist irrigation, and the substrate was allowed to settle for 24 h. The greenhouse was maintained at 30/26 C day/night temperatures with a 16-h photoperiod supplemented by overhead sodium halide lamps with a light intensity of 450 μ mol s^{-1}.

For the preemergence efficacy experiment, indaziflam was applied on June 9, 2022 (the first run) and May 30, 2023 (the second run) 49, 98, or 196 g ha^{-1} with a compressed CO_2 research plot sprayer calibrated to deliver a spray volume of 187 L ha^{-1} through a single TeeJet flat-fan AI8002VS spray nozzle at 207 kPa and 1.3 m s^{-1}. Each indaziflam treatment was applied to 24 containers (six single-container replications per weed species). After treatment application, containers were placed back in the greenhouse under the overhead mist irrigation system, and 1.25-cm irrigation was applied. Approximately 4 h after overhead irrigation, 50 seeds of either creeping woodsorrel (*Oxalis corniculata* L.), hairy bittercress (*Cardamine hirsuta* L.), giant foxtail, or large crabgrass were planted with a shaker vial individually on the surface of each of the six containers per treatment. The experiment was established in a completely randomized design with six containers per weed species per treatment. An untreated control (six containers per weed species) was also included for treatment comparison. An overhead mist irrigation of 1.25 cm was applied daily in four cycles of 4 min each with 3 h between cycles.

For the early postemergence efficacy experiment, approximately 50 seeds of creeping woodsorrel, fringed willowherb (*Epilobium ciliatum* Raf.), hairy bittercress, or mouse-ear chickweed (*Cerastium vulgatum* L.) were planted individually on June 9, 2022 (the first run) and May 30, 2023 (the second run) with a shaker vial on the surface of each of the six containers per herbicide treatment. Containers were regularly watered with overhead mist irrigation of 1.25 cm applied daily in four cycles of 4 min each with 3 h between cycles. On June 28, 2022 (the first run) and June 21, 2023 (the second run), indaziflam was applied to the emerged seedlings of creeping woodsorrel (1- to 2-leaf stage), fringed willowherb (4- to 6-leaf stage), hairy bittercress (cotyledon to 1-leaf stage), and mouse-ear chickweed (2- to 4-leaf stage) using the same application rates, volume, and method as used in the preemergence efficacy experiment. Each indaziflam treatment was applied to 24 containers (six single container replications per weed species). An untreated control (six container per weed species) was also maintained for treatment comparison. The experiment was established in a completely randomized design, with six containers per treatment per weed species. After treatment application, containers were placed back in the greenhouse under the overhead mist irrigation system, and the regular watering schedule was resumed 4 h after the early postemergence treatment.

Data Collection

Data were recorded on ornamental plant injury (chlorosis, necrosis, and stunting) at both locations, and weed control in the Connecticut experiments. Phytotoxicity ratings for chlorosis, necrosis, and stunting injury were recorded at 7, 14, and 28 d after each treatment on a 0 to 10 scale with 0 = no damage, 1 = minor (10%), 2 = moderate (20%), 2–4 = severe (20% to 40%), 5–9 = extreme (50% to 90%), and 10 = plant death. The final plant height or width was recorded at 35 d after the second application. Preemergence weed control was visibly evaluated by counting the number of weeds germinated in each pot at 14 and 28 d after preemergence treatment. Visible estimates of postemergence weed control, as compared with the untreated control, were recorded at 14 and 28 d after postemergence treatment on a 0% to 100% scale where 0 = no control and 100 = plant death. At 28 d after preemergence/ or days after postemergence, all weeds, where present, were manually clipped from each pot, and the shoot fresh biomass was recorded.

Statistical Analysis

Data on various response variables were analyzed with a generalized linear mixed model methodology using the GLIMMIX procedure in SAS (v. 9.3; SAS Institute, Inc., Cary, NC). Before the ANOVA test, data were tested for normality using the UNIVARIATE procedure and homogeneity of variance with the modified Levene test. Ornamental plant injury, height, and width data were analyzed individually by plant species and application (first or second). The weed control, density, and fresh biomass data were analyzed separately by weed species. The weed control and density data were arcsine-transformed, and the fresh biomass data were square root–transformed to correct non-normality and heterogeneity of variance. However, the back-transformed means are discussed and presented in the tables for simplicity. The indaziflam rate was treated as a fixed effect, whereas year (experiment run), replication, and their interactions with fixed effect factors were considered random. Means were separated with Fisher's protected least square difference at $\alpha = 0.05$.

Results and Discussion

Crop Safety

At both locations, ornamental plant species tested in this study tolerated indaziflam very well. No chlorotic, necrotic, or stunting

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Table 2. Final plant height and width of ornamental plant species tested in Connecticut at different rates of indaziflam.[a]

	Chinese pyramid juniper		Common juniper		Eastern hemlock		Eastern white pine	Norway spruce
Indaziflam[b]	Height	Width	Height	Width	Height	Width	Height	Height
g ha^{-1}	cm							
0	29 a	21 a	26 a	33 a	27 a	31 a	36 a	52 a
49	27 a	23 a	28 a	35 a	28 a	29 a	32 a	56 a
98	25 a	25 a	25 a	31 a	26 a	30 a	35 a	55 a
196	27 a	23 a	25 a	32 a	27 a	30 a	34 a	53 a

[a]Means followed by the same letters within a column are not significantly different using Fisher's protected least square difference at α = 0.05. Data were averaged over 2 yr.
[b]Indaziflam was first applied within 5 d after transplant, and again approximately 6 wk after the first application using a compressed CO_2 research plot sprayer.

Table 3. Final plant height and width of ornamental plant species tested in Tennessee at different rates of indaziflam herbicide.[a]

	'Andorra Compacta' creeping juniper		'Black Dragon' Japanese ceder		'Blue Rug' creeping juniper		'Blue Pfitzer' Chinese juniper	
Indaziflam[b]	Height	Width	Height	Width	Height	Width	Height	Width
g ha^{-1}	cm							
0	26 a	37 a	27 a	14 a	11 a	15 a	22 a	19 a
49	26 a	38 a	28 a	14 a	10 a	15 a	21 a	23 a
98	25 a	35 a	27 a	13 a	9 a	14 a	22 a	23 a
196	24 a	35 a	28 a	14 a	10 a	13 a	21 a	22 a

[a]Means followed by the same letters within a column are not significantly different using Fisher's protected least square difference at α = 0.05.
[b]Indaziflam was first applied within 5 d after transplant, and again approximately 6 wk after the first application using a compressed CO_2 research plot sprayer.

Table 4. Number of plants per pot for four weed species after preemergence application of indaziflam herbicide.[a,b]

	Creeping woodsorrel		Hairy bittercress		Giant foxtail		Large crabgrass	
Indaziflam[c]	14 DAPRE	28 DAPRE	14 DAPRE	28 DAPRE	14 DAPRE	28 DAPRE	14 DAPRE	28 DAPRE
g ha^{-1}	plants pot^{-1}							
0	21 a	23 a	26 a	22 a	31 a	25 a	19 a	25 a
49	3 b	1 b	6 b	2 b	9 b	2 b	11 b	7 b
98	0 c	0 c	0 c	0 c	2 c	0 c	7 b	2 c
196	0 c	0 c	0 c	0 c	0 d	0 c	1 c	0 d

[b]Densities were averaged over two experimental runs. Means followed by the same letters within a column are not significantly different using Fisher's protected least square difference at α = 0.05.
[c]Indaziflam was applied on June 9, 2022 (the first run) and May 30, 2023 (the second run) with a compressed CO_2 research plot sprayer through a single flat-fan AI8002VS spray nozzle.

Table 5. Fresh shoot biomass of four weed species 28 d after preemergence application of indaziflam.[a,b]

Indaziflam	Creeping woodsorrel	Hairy bittercress	Giant foxtail	Large crabgrass
g ha^{-1}	g pot^{-1}			
0	8.3 a	6.1 a	8.2 a	9.4 a
49	0.3 b	0.4 b	0.2 b	1.3 b
98	0.0 c	0.0 c	0.0 c	0.3 b
196	0.0 c	0.0 c	0.0 c	0.0 c

[a]Shoot fresh biomass data were averaged over two experimental runs. Means followed by the same letters within a column are not significantly different using Fisher's protected least square difference at α = 0.05.
[b]Indaziflam was applied on June 9, 2022 (the first run), and May 30, 2023 (the second run), with a compressed CO_2 research plot sprayer through a single flat-fan AI8002VS spray nozzle.

injury was observed when two sequential applications of indaziflam at rates up to 196 g ha^{-1} were made at 6-wk intervals. Final plant height and width data revealed no differences between the indaziflam rates tested in this study and the untreated control (Tables 2 and 3). Other researchers found indaziflam to be highly safe for these species when applied at similar rates (Palmer 2022).

Weed Efficacy

Preemergence Efficacy

Indaziflam provided preemergence control of all four weed species, but the level of control varied by application rate. In the untreated control, the number of plants per pot ranged 19 large crabgrass to 31 giant foxtail at 14 d after preemergence. Fewer plants per pot were recorded with all indaziflam rates (Table 4). At the 49 g ha^{-1} rate, indaziflam reduced densities of creeping woodsorrel, hairy bittercress, giant foxtail, and large crabgrass by 42% to 86% at 14 d after preemergence and by 72% to 95% at 28 d after preemergence compared with the untreated control. At the 98 g ha^{-1} rate, weed densities were reduced by 63% to 100% at 14 d after preemergence and by 92% to 100% at 28 d after preemergence. When indaziflam was applied at 196 g ha^{-1}, creeping woodsorrel, hairy bittercress, and giant foxtail were completely controlled (0 plants per pot) at 14 d after

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Table 6. Early postemergence control of four weed species after application of indaziflam.[a,b,c]

Indaziflam	Creeping woodsorrel		Fringed willowherb		Hairy bittercress		Mouse-ear chickweed	
	14 DAPOST	28 DAPOST	14 DAPOST	28 DAPOST	14 DAPOST	28 DAPOST	14 DAPOST	28 DAPOST
g ha^{-1}	% control							
49	92 b	97 a	99 a	99 a	73 b	88 a	46 c	76 b
98	96 a	99 a	99 a	99 a	95 a	99 a	68 b	87 a
196	99 a	99 a	99 a	99 a	99 a	99 a	89 a	99 a

[a]Abbreviation: DAPRE, days after preemergence application of indaziflam.
[b]Weed control data were averaged over two experimental runs. Means followed by the same letters within a column are not significantly different using Fisher's protected least square difference at α = 0.05.
[c]Indaziflam was applied on June 28, 2022 (the first run), and June 21, 2023 (the second run), with a compressed CO_2 research plot sprayer through a single flat-fan AI8002VS spray nozzle.

Table 7. Fresh shoot biomass of four weed species 28 d after an early postemergence application of indaziflam.[a,b]

Indaziflam	Creeping woodsorrel	Fringed willowherb	Hairy bittercress	Mouse-ear chickweed
g ha^{-1}	g pot^{-1}			
0	12.7 a	9.1 a	7.4 a	14.3 a
49	0.3 b	0.0 b	0.9 b	3.1 b
98	0.0 b	0.0 b	0.0 b	1.5 c
196	0.0 b	0.0 b	0.0 b	0.0 c

[a]Indaziflam was applied on June 28, 2022 (the first run), and June 21, 2023 (the second run), with a compressed CO_2 research plot sprayer through a single flat-fan spray nozzle AI8002VS spray nozzle.
[b]Shoot fresh biomass data were averaged over two experimental runs. Means followed by the same letters within a column are not significantly different using Fisher's protected least square difference at α = 0.05.

preemergence and thereafter. Large crabgrass densities were reduced by 95% and 100% at 14 and 28 d after preemergence, respectively.

Fresh shoot biomass at 28 d after preemergence was significantly reduced for all indaziflam rates compared with the untreated control (Table 5). At the 49 g ha^{-1} rate of indaziflam, fresh shoot biomass was reduced by 96%, 93%, 97%, and 86% for creeping woodsorrel, hairy bittercress, giant foxtail, and large crabgrass, respectively. Complete control (100% reduction in fresh shoot biomass) occurred for all weeds at 98 and 196 g ha^{-1} rates except for large crabgrass at the 98 g ha^{-1} rate (96% reduction).

Indaziflam is an alkylazine class herbicide labeled for control of 85 broadleaf, grass, and sedge weeds from seed by inhibiting cellulose biosynthesis (Anonymous 2024; Brosnan et al. 2011). Preemergence applications of indaziflam have been previously reported to control large crabgrass and giant foxtail by 99% and 90% respectively, at the 40 g ha^{-1} rate (Aulakh 2020). Similarly, indaziflam provided more than 95% control of flexuous bittercress (*Cardamine flexuosa* With.), a species closely related to the hairy bittercress used in our study (Edwards et al. 2015). McCullough et al. (2013) reported 84% to 100% control of goosegrass (*Eleusine indica*) when indaziflam was applied at 70 g ha^{-1}. In the current study, indaziflam provided more than 85% control of four common weeds species at 28 d after preemergence but 3 to 5 mo of residual weed control can be expected (Jhala and Singh 2012).

Postemergence Efficacy

Results revealed an excellent control (≥92%) of creeping woodsorrel and fringed willowherb at 14 and 28 d after postemergence when indaziflam was applied at rates of 49 to 196 g ha^{-1} (Table 6). These results are consistent with those reported by Marble et al. (2013), who previously recorded an 87% to 100% control of 2- to 4-leaf yellow woodsorrel (*Oxalis stricta*), a closely related species to creeping woodsorrel, 14 to 28 d after a postemergence application of indaziflam (975 g ha^{-1}) in container experiments. In separate nursery trials, Marble et al. (2016) also found that indaziflam was quite effective (>90% control) in controlling yellow woodsorrel than the granular formulation of indaziflam (0% to 53% control) when applied postemergence (2- to 4-leaf and 6- to 8-leaf growth stages) at 12 or 25 g ha^{-1} rates. In that same study, no differences were observed between suspension concentrate or granular formulations of indaziflam for control of yellow woodsorrel, when applied postemergence at 49 or 98 g ha^{-1} rates (Marble et al. 2016). In the current study, the postemergence application of indaziflam at 49 g ha^{-1} provided only 73% to 88% control of hairy bittercress at 14 and 28 d after postemergence; however, greater control (≥95%) was achieved when indaziflam was applied at 98 or 196 g ha^{-1} (Table 6). Among all four weed species tested, the least control (46% to 76%) was observed with mouse-ear chickweed at 14 and 28 d after a postemergence application of indaziflam at 49 g ha^{-1}. Increasing rates of indaziflam from 98 to 196 g ha^{-1} resulted in improved visual control of mouse-ear chickweed from 68% to 89% at 14 d after postemergence and 87% to 99% at 28 d after postemergence (Table 6).

Consistent with percent visual control, the postemergence applications of indaziflam at 49 to 196 g ha^{-1} significantly reduced fresh shoot biomass of creeping woodsorrel, fringed willowherb, hairy bittercress, and mouse-ear chickweed at 28 d after postemergence. For instance, indaziflam applied postemergence across all tested rates resulted in 88% to 100% reduction in fresh shoot biomass (compared with untreated plants) of creeping woodsorrel, fringed willowherb, and hairy bittercress (Table 7). Across all four weed species and three tested rates of indaziflam, the least reduction in fresh shoot biomass (78% compared with the untreated control) was observed in mouse-ear chickweed with postemergence application of indaziflam at 49 g ha^{-1} (Table 7). However, the fresh shoot biomass reduction of mouse-ear chickweed was 89% to 100% (compared with a nontreated weedy check) with postemergence indaziflam applied at 98 or 196 g ha^{-1}.

Practical Implications

With limited preemergence and postemergence herbicide options for use on ornamental plants, the excellent crop safety and weed control exhibited by indaziflam in this study is important. Results suggest that indaziflam applied preemergence and postemergence at various rates was safe on Chinese pyramid juniper, common juniper, eastern hemlock, eastern white pine, Norway spruce, Andorra Compacta creeping juniper, Black Dragon Japanese cedar, Blue Rug creeping juniper, and Blue Pfitzer Chinese pyramid juniper. Presently, Chinese pyramid juniper, eastern hemlock, eastern white pine, Norway spruce, Black Dragon Japanese cedar, Blue Rug creeping are listed as being tolerant to the indaziflam herbicide label. Common juniper (*Juniper* × *media*), 'Andorra Compacta' creeping juniper, and 'Blue Pfitzer' Chinese

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juniper were found to be equally tolerant and may also be added to the indaziflam herbicide label.

Furthermore, indaziflam (depending upon the use rates) effectively controlled creeping woodsorrel, hairy bittercress, giant foxtail, and large crabgrass when applied preemergence; and creeping woodsorrel, fringed willowherb, hairy bittercress, and mouse-ear chickweed when applied postemergence. The early postemergence efficacy of indaziflam offers an added weed control advantage. Most nursery weed managers apply a preemergence herbicide in the fall (to control winter annual weeds) before container ornamentals are transferred into the overwintering structures. Usually, a preemergence herbicide is usually expected to degrade more than 87% by 12 wk after treatment (Devlin et al. 1992). Therefore, weeds such as chickweeds, common groundsel, hairy bittercress, and fringed willowherb often emerge before receiving a preemergence herbicide treatment in the following spring. When applied in spring after overwintering, indaziflam can eliminate or significantly reduce the need for hand removal of existing weeds. However, it is critical to note that overreliance on indaziflam should be avoided to prevent the evolution of indaziflam-resistant weeds. Therefore, to safeguard the weed efficacy of indaziflam, growers should also integrate other weed control tactics, including sanitation, alternate herbicide sites of action, and physical methods for weed control in ornamental plant production. Future studies should assess the efficacy of indaziflam applied preemergence or postemergence alone or in combination with other herbicides for crop safety on additional ornamental plants and control of other weed species.

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