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Short title: Indaziflam in ornamentals

Ornamental Plant Safety and Weed Control with Indaziflam

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Abstract

Indaziflam was evaluated in Connecticut and Tennessee, USA, 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 preemergence or early postemergence to weeds in greenhouse. Ornamental plants were treated twice annually in 2020 and 2021 in Connecticut, and in 2019 and 2020 in Tennessee, with approximately six weeks between applications. Chinese pyramid juniper, common juniper, eastern hemlock, eastern white pine, and Norway spruce in Connecticut, USA, and 'Andorra Compacta' creeping juniper and 'Black Dragon' Japanese cedar, ‘Blue Rug’ creeping juniper, and ‘Blue Pfitzer’ Chinese pyramid juniper in Tennessee, USA, were not injured with indaziflam regardless of rate applied. Preemergence application of indaziflam reduced densities of creeping woodsorrel, hairy bittercress, giant foxtail, and large crabgrass 72 to 100%, depending upon 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 the 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.

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

Nomenclature: 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.; Giant foxtail, *Setaria faberi* Herrm.; hairy bittercress, *Cardamine hirsute* L.; Large crabgrass, *Digitaria sanguinalis* (L.) Scop.; Norway spruce, *Picea abies* (L.) H. Karst.

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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 (PRE) herbicides and hand weeding for weed management (Altland et al. 2004). Manual weed control is costly because of increasing labor expenses. Annually, nurserymen spend $500 to $4,000 yearly on hand weeding (Mathers 2003). Hand weeding one thousand 3-L pots over four months 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 high as $17,300 per ha (Case et al. 2005).

Preemergence herbicides offer broad-spectrum, economical, and long-duration weed control. Recently, indaziflam (Marengo®; Bayer CorpScience LP., Cary, NC) has been registered for control of broadleaf weeds, grasses, and sedges in container- and field-grown ornamentals, conifers and Christmas tree plantations, non-bearing fruit and nut trees, greenhouse floors, 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 [WSSA]), 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, affecting cell wall formation, cell division, and cell elongation in the growing meristematic regions of emerging seeds (Anonymous 2024). Indaziflam offers PRE and early postemergence (EPOST) activity on grass and broadleaf weeds.

Several previous studies have reported indaziflam applied PRE or EPOST to be 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 other herbicides like dithiopyr, prodiamine, and oxadiazon. Besancon and Bouchelle (2023) found fall applications of indaziflam at 146 g ha^{-1} to be more effective in controlling horseweed and large crabgrass than spring applications in northern highbush blueberry (*Vaccinium corymbosum* L.). Similarly,

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Aulakh (2020) reported >80% of season-long control for giant foxtail, horseweed, large crabgrass, and redroot pigweed when indaziflam was applied PRE at 40 g ha^{-1} in Canaan fir (*Abies balsamea var.phanerolepis*) before bud-break.

Indaziflam has been evaluated for crop tolerance in many specialty crops, including Christmas trees, non-bearing 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. 2019; 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.), hostas (*Hosta* spp.), hydrangeas (*Hydrangea* spp.), phlox (*Phlox paniculata*), purple coneflower (*Echinacea purpurea*), salvia (*Salvia sylvestris*), and zinnia (*Zinnia* spp.) 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 indaziflam's crop safety on various container-grown ornamentals and its effectiveness in PRE or early POST (EPOST) weed control.

Materials and Methods

Crop Safety Experiments. Indaziflam (Marengo®; Bayer CorpScience LP., Cary, NC) 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 in CT and TN are given in Table 1.

In CT, 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 CT experiments 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}

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booster micronutrients (Harrells LLC, Lakeland, FL), and 1.7 kg m^{-3} dolomitic limestone (Plant Products LLC, Findley, OH). In TN, ornamental plants were transplanted into 3.7 L (C400) or 2.3 L (C300S) containers (Nursery Supplies Inc., Chambersburg, PA) filled with pine bark (Morton's Horticultural Products, McMinnville, TN). For TN experiments, 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 LLC, Findley, OH). 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 CT (Table 1). In TN experiments, different plant species were evaluated in 2020 (Table 1). The experiment was arranged in a completely randomized design with 12 replications per treatment.

In CT experiments, indaziflam was applied to the new growth approximately 3 weeks after transplanting (Table 1). In TN experiments, 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®; Spraying Systems Co., Wheaton, IL) in CT or TN, 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 was made approximately 6 weeks 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 98 or 196 g ha^{-1} rate in this study was above the maximum labeled rates for a single application. All ornamental plant species received 1.25-cm overhead irrigation approximately 2 h after treatment application and daily thereafter.

Weed Efficacy Experiments. Indaziflam was evaluated for PRE or EPOST 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 PRE or EPOST experiment run, 96 containers (9-cm diameter; SVD350, T.O. Plastics) were filled with the Pro-Mix Premium All Purpose planting media (200 Kelly Rd, Quakertown, PA 18951). Pro-Mix Premium All Purpose contains Canadian sphagnum peat moss (80-90%), peat humus, perlite, limestone, and mycorrhizae PTB297 technology. Containers were watered

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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 PRE 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 flat-fan spray nozzle AI8002VS (TeeJet®; Spraying Systems Co., Wheaton, IL) 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*), hairy bittercress (*Cardamine hirsuta*), 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 EPOST efficacy experiment, approximately 50 seeds of creeping woodsorrel, fringed willowherb (*Epilobium ciliatum*), hairy bittercress, or mouse-ear chickweed (*Cerastium vulgatum*) were planted on June 9, 2022 (the first run) and May 30, 2023 (the second run) with a shaker vial individually 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 PRE 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

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overhead mist irrigation system, and the regular watering schedule was resumed 4 h after the EPOST treatment.

Data Collection. Data were recorded on ornamental plant injury (chlorosis, necrosis, and stunting) in CT and TN and weed control in CT experiments. Phyto-toxicity 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 = dead plant. 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 (DAPRE). Visible estimates of postemergence weed control, as compared to the untreated control, were recorded at 14 and 28 d after POST treatment (DAPOST) on a 0 to 100% scale where 0=no control and 100 = dead plant. At 28 DAPRE/DAPOST, 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 (Version 9.3; SAS Institute, Inc., Cary, NC). Before the ANOVA test, data were tested for normality using PROC UNIVARIATE 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 injury was observed when two sequential applications of indaziflam at rates up to 196 g ha^{-1} were made at 6-week intervals. Final plant height and width data revealed no differences between the indaziflam rates tested in this study

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and the untreated control (Tables 2 and 3). Other researchers found indaziflam to be highly safe for these species at similar rates (Palmer 2022).

Weed efficacy

PRE-Efficacy. Indaziflam provided PRE control of all four weed species, but the level of control varied by the application rate. In the untreated control, the number of plants per pot ranged 19 for large crabgrass to 31 for giant foxtail at 14 DAPRE. The number of plants per pot was lower for all indaziflam rates for each weed species (Table 4). At 49 g ha^{-1} rate, indaziflam reduced densities of creeping woodsorrel, hairy bittercress, giant foxtail, and large crabgrass by 42 to 86% at 14 DAPRE and 72 to 95% at 28 DAPRE compared with the untreated control. At 98 g ha^{-1} rate, weed densities were reduced by 63 to 100% at 14 DAPRE and 92 to 100% at 28 DAPRE. 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 DAPRE and thereafter. Large crabgrass densities were reduced by 95% and 100% at 14 and 28 DAPRE, respectively.

Fresh shoot biomass at 28 DAPRE was significantly reduced for all indaziflam rates compared to the untreated control (Table 5). At 49 g ha^{-1} rate of indaziflam, fresh shoot biomass was reduced 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 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, 99 and 90% respectively, at 40 g ha^{-1} rate (Aulakh 2020). Similarly, indaziflam provided over 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 over 85% control of four common weeds species at 28 DAPRE but 3 to 5 months of residual weed control can be expected (Jhala and Singh 2012).

POST-Efficacy. Results revealed an excellent control (≥92%) of creeping woodsorrel and fringed willowherb at 14 and 28 DAPOST when indaziflam was applied at rates of 49 to 196 g

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ha^{-1} (Table 6). These results are consistent with Marble et al. (2013), who previously reported 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 POST application of indaziflam (975 g ha^{-1}) in container experiments. In separate nursery trials, Marble et al. (2016) also found that the indaziflam was quite effective (> 90% control) in controlling yellow woodsorrel than the granular formulation (G) of indaziflam (0 to 53% control) when applied POST (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 SC or G formulations of indaziflam for control of yellow woodsorrel, when applied POST at 49 or 98 g ha^{-1} rates (Marble et al. 2016). In the current study, the POST application of indaziflam at 49 g ha^{-1} only provided 73 to 88% control of hairy bittercress at 14 and 28 DAPOST; 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 for mouse-ear chickweed at 14 and 28 DAPOST with 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 DAPOST and 87 to 99% at 28 DAPOST (Table 6).

Consistent with percent visual control, the POST 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 DAPOST. For instance, the POST applied indaziflam across all tested rates resulted in 88 to 100% reduction in fresh shoot biomass (as compared to the untreated) 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% as compared to the untreated control) was observed for mouse-ear chickweed with POST application of indaziflam at 49 g ha^{-1} (Table 7). However, the fresh shoot biomass reduction of mouse-ear chickweed was 89 to 100% (as compared to nontreated weedy check) with POST indaziflam applied at 98 or 196 g ha^{-1}.

Practical Implications. With limited PRE and POST herbicide options for use in ornamental plants, the excellent crop safety and weed control exhibited by indaziflam in this study is important. Results suggested that indaziflam applied PRE and POST 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,

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eastern white pine, Norway spruce, Black Dragon Japanese cedar, Blue Rug creeping are listed as tolerant species on the indaziflam herbicide label. Common juniper (*Juniper x media*), 'Andorra Compacta' creeping juniper, and 'Blue Pfitzer' Chinese juniper were found 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 PRE and creeping woodsorrel, fringed willowherb, hairy bittercress, and mouse-ear chickweed when applied POST. The early POST efficacy of indaziflam offers an added weed control advantage. Most nursery weed managers make a fall PRE herbicide application (to control winter annual weeds) before container ornamentals are transferred into the overwintering structures. Usually, a PRE herbicide is usually expected to degrade more than 87% by 12 weeks after treatment (Devlin et al. 1992). Therefore, weeds like chickweeds, common groundsel, hairy bittercress, and fringed willowherb often emerge before a PRE 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 weed populations. 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 plants. Future studies should assess the efficacy of indaziflam applied PRE or POST alone or in combination with other herbicides for crop safety on additional ornamental plants and control of other weed species.

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Table 1. Ornamental plant species and materials used in Connecticut and Tennessee, USA, crop safety experiments from 2019- 2021.

Site	Ornamental Species	Plug/liner size	Container size	Transplanting date	1st indazilflam application	2nd indazilflam application	Application Volume
			L				L ha^{-1}
CT	Chinese pyramid juniper (*Juniperus chinensis*)	(6- x 6-cm), 12-to 18-cm	5.6	5/8/2020, 5/26/2021	6/1/2020, 6/18/2021	7/9/2020, 7/28/2021	187
	common juniper (*Juniperus x media*)	(6- x 6-cm), 10-to 15-cm	5.6	5/8/2020, 5/26/2021	6/1/2020, 6/18/2021	7/9/2020, 7/28/2021	187
	eastern hemlock (*Tsuga canadensis*)	(2+1), 20- to 25-cm	5.6	5/8/2020, 5/26/2021	6/1/2020, 6/18/2021	7/9/2020, 7/28/2021	187
	eastern white pine (*Pinus strobus*)	(3+1), 25- to 30-cm	5.6	5/8/2020, 5/26/2021	6/1/2020, 6/18/2021	7/9/2020, 7/28/2021	187
	Norway spruce (*Picea abies*)	(2+2), 35- to 45-cm	5.6	5/8/2020, 5/26/2021	6/1/2020, 6/18/2021	7/9/2020, 7/28/2021	187
TN	'Andorra Compacta' creeping juniper (*Juniperus horizontalis*)	(10- x 10-cm), 20- to 22-cm	3.7	6/7/2019	6/11/2019	7/24/2019	281
	'Black Dragon' Japanese cedar	32-cell flat, 25-cm	3.7	6/7/2019	6/11/2019	7/24/2019	281

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(*Cryptomeria japonica*)						
‘Blue Rug’ creeping juniper (*Juniperus horizontalis*)	60-cell flat, 8- to 10-cm	2.3	8/4/2020	8/6/2020	9/18/2020	281
‘Blue Pfitzer’ Chinese juniper (*Juniperus chinensis*)	60-cell flat, 15- to 20-cm	2.3	8/4/2020	8/6/2020	9/18/2020	281

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

Indaziflam	Chinese pyramid juniper		Common juniper		Eastern hemlock		Eastern white pine	Norway spruce
	Height	Width	Height	Width	Height	Width	Height	Height
	---cm---							
g ha^{-1}								
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] Indaziflam (Marengo® SC, Bayer CropScience, LP., Cary, NC); the first application was made within 5 d after transplant, and a second application was applied ~ 6 wk after the first application using a compressed CO_2 research plot sprayer.

[b] Means followed by the same letters within a column are not significantly different using Fisher's protected least square difference at $\alpha = 0.05$. Data averaged over two years.

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

Indaziflam	'Andorra Compacta' creeping juniper		'Black Dragon' Japanese ceder		'Blue Rug' creeping juniper		'Blue Pfitzer' Chinese juniper	
	Height	Width	Height	Width	Height	Width	Height	Width
	--cm--							
g ha^{-1}	---							
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] Indaziflam (Marengo® SC, Bayer CropScience, LP., Cary, NC); the first application was made within 5 d after transplant, and a second application was applied ~ 6 wk after the first application using a compressed CO_2 research plot sprayer.

[b] Means followed by the same letters within a column are not significantly different using Fisher's protected least square difference at $\alpha = 0.05$.

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

Indaziflam	Creeping woodsorrel		Hairy bittercress		Giant foxtail		Large crabgrass	
	14 DAPRE	28 DAPRE	14 DAPRE	28 DAPRE	14 DAPRE	28 DAPRE	14 DAPRE	28 DAPRE
	--plants pot^{-1}--							
g ha^{-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

[a] Indaziflam (Marengo® SC; Bayer Environmental Science, Cary, NC, USA) 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 spray nozzle AI8002VS.

[b] DAPRE=days after preemergence application of indaziflam.

[c] 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.

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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] Indaziflam (Marengo® SC; Bayer Environmental Science, Cary, NC, USA) 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 spray nozzle AI8002VS.

[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 $\alpha = 0.05$.

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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] Indaziflam (Marengo® SC; Bayer Environmental Science, Cary, NC, USA) 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.

[b] DAPOST=days after early postemergence application of indaziflam.

[c] 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 $\alpha = 0.05$.

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Table 7. Fresh shoot biomass of four weed species 28 d after 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 (Marengo® SC; Bayer Environmental Science, Cary, NC, USA) 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.

[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.

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