Evaluation of Indaziflam for Greenhouse Use[1]

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Abstract

Due to the relatively small market, volatility concerns, and high crop-value-per-acre associated with ornamental crops, no preemergence (PRE) herbicides are currently labeled for use in greenhouses containing plants. The objective of this study was to evaluate indaziflam SC for potential use as a PRE herbicide on gravel in greenhouses containing sensitive crops grown in extreme environmental conditions. Mini-greenhouses (MG) were designed and constructed to fit within gravel ground beds as an initial component to this study in order to evaluate herbicide volatility. Species evaluated included 'Better Boy' tomato (*Lycopersicon esculentum* Mill.), 'Extreme Orange' impatiens (*Impatiens walleriana* Hook. f.) and two species of petunia (*Petunia* × *hybrida* Juss. 'Dreams White' and 'Dreams Neon Rose'). Indaziflam SC was applied at the manufacturer's labeled rate [40 g ai·ha^{-1} (0.04 lbs ai·A^{-1})] (1×) and at twice the labeled rate [80 g ai·ha^{-1} (0.07 lbs ai·A^{-1})] (2×). Each rate was applied using one of three different methods: 1) applied to only the gravel in ground beds with plants placed on gravel and covered with MG immediately following application; 2) applied over the top of plants on gravel inside the ground beds and covered with MG immediately application; and 3) applied over the top of plants outside the ground beds on adjacent gravel and left outside of MG. Two nontreated control treatments were maintained for each species and were placed either on nontreated gravel inside ground beds and covered with MG or placed outside ground beds on adjacent nontreated gravel and not covered with MG. Little to no injury was observed on any of the species after being placed on treated gravel and covered with a MG regardless of indaziflam rate. However when indaziflam was applied over-the-top, impatiens and tomatoes exhibited severe injury and death by 30 days after treatment (DAT). Additionally, fresh weights showed that all species receiving either over-the-top treatment were severely injured, while the plants placed on treated gravel inside the MG and both nontreated control treatments (both inside and outside of MG) exhibited no signs of injury or stunted growth. Results from this study indicate that while indaziflam may cause crop injury to ornamental species when applied over-the-top, it is likely that little to no injury will be observed as a result of volatility due to a gravel application in an enclosed structure.

Index words: annual production, over-the-top, herbicide, preemergence, volatility.

Species used in this study: tomato (*Lycopersicon esculentum* Mill. 'Better Boy'), impatiens (*Impatiens walleriana* Hook. f. 'Extreme Orange'), petunia (*Petunia* × *hybrida* Juss. 'Dreams White', *Petunia* × *hybrida* Juss. 'Dreams Neon Rose').

Herbicides used in this study: Indaziflam SC[N-[(1R,2S)-2,3-dihydro-2,6-dimethyl-1H-inden-1-yl]-6-[(1RS)-1-fluoroethyl]-1,3,5-triazine-2,4-diamine].

Significance to the Horticulture Industry

Due to the liability associated with high value ornamental crops and volatility concerns, there are currently no PRE herbicides labeled for use in enclosed structures containing plants. Indaziflam SC is a new PRE herbicide for nursery crop production and has a low volatility index, which makes it a viable option in production areas such as greenhouses. The objective of this study was to evaluate indaziflam as a PRE herbicide for use in greenhouses currently in production. Data reported in this study indicate that while indaziflam SC may cause significant crop injury if applied over the top of ornamental crops, it caused little to no crop injury when applied to gravel ground beds in a greenhouse structure while the crops were exposed to extreme environmental conditions, indicating that volatility is likely not a concern when applying indaziflam inside an enclosed structure, such as a greenhouse.

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Introduction

Indaziflam is a new preemergence (PRE) herbicide that has been recently made available to landscapers and nursery growers. Indaziflam is classified as an alkylazine herbicide and a cellulose biosynthesis inhibitor, inhibiting crystalline cellulose deposition in the cell wall, affecting wall formation, cell elongation, and division and only affects growing meristematic regions of emerging seeds (Anonymous 2009, Brabham et al. 2014). Compared to most PRE herbicides such as dinitroanilines, indaziflam has a longer half-life in the soil (>150 d) which makes it a desirable weed control tool (Brosnan et al. 2011). As it is a newer chemistry, relatively little research has been published evaluating indaziflam efficacy or crop tolerance in ornamental production; however, indaziflam is labeled to control over 85 broadleaf, grass, and sedge weeds from seed (Anonymous 2014). Previous work has shown that indaziflam provides effective PRE and early-postemergence smooth crabgrass (*Digitaria ischaemum* (Schreb.) Muhl.) (Brosnan et al. 2011) and yellow woodsorrel (*Oxalis stricta* L.) control (Marble et al. 2013). Brosnan et al. (2012) also reported effective PRE control of annual bluegrass (*Poa annua* L.) with indaziflam at rates of 30 g ai·ha^{-1} (0.03 lb ai·A^{-1}) to 60 g ai·ha^{-1} (0.05 lb ai·A^{-1}). Additional research has shown that indaziflam provides effective PRE control of goosegrass (*Eluesine indica* L.) (McCullough et al. 2013) and in field studies has shown PRE efficacy on common chickweed (*Stellaria media* L.), field bindweed (*Convovulus arvensis* L.) (Hanson and Jhala 2010), eclipta (*Eclipta prostrata* L.), Brazil pusley (*Richardia brasiliensis* Moq.), and cock's-comb kyllinga (*Kyllinga squamulata* Thonn. Ex Vahl)] when reproducing by seed (Jhala et al. 2013, Perry et al. 2011). Additional research has shown that indaziflam provides over 95% control of common nursery and greenhouse weeds including flexuous bittercress (*Cardamine flexuosa* With.), spotted spurge (*Chamaesyce maculata* L.) and artillery weed (*Pilea microphylla* L.) (Marble 2014, 2015; unpublished data). Application placement of indaziflam for postemergence (POST) control of smooth crabgrass and annual bluegrass was evaluated in a greenhouse study by Brosnan and Breeden (2012). Results showed soil-plus-foliar and soil-only applications to have greater POST efficacy than foliar-only applications, suggesting root absorption is required for POST control of smooth crabgrass and annual bluegrass.

Although previous indaziflam evaluations have predominately focused on weed control in turfgrass, indaziflam is also now labeled as a directed application around woody ornamentals and can be applied to non-crop production areas in ornamental nurseries. Researchers are currently evaluating indaziflam on new crops, weeds, and in different production schemes in order to expand the label in the ornamental market. One area in which growers are constantly struggling to control weeds is inside enclosed structures, such as greenhouses. Due to the liability associated with high value ornamentals crops and volatility concerns, chemical manufacturers have been hesitant in the past to develop or market PRE herbicides for use in greenhouses. Indaziflam is currently labeled for use inside enclosed structures, but during application the greenhouse can contain no plant species and houses must be ventilated for 24 h after application before plants are re-introduced (Anonymous 2014).

Finding a product to provide effective PRE control of weeds inside greenhouses during production would be significant because ornamental plant production is generally far less mechanized than other agricultural sectors. Container-grown crops must be weed-free in order to be marketable, not only because weed-free containers are more aesthetically pleasing, but crop growth may also be significantly reduced by the presence of weeds (Fretz 1972). The cost of hand labor to pull weeds is a major production cost for growers. Due to recent immigration laws in Alabama and other states, labor is now hard to find in many areas (Johnson 2011), making weed control inside enclosed structures even more difficult. To avoid risking crop injury from herbicide volatility, growers must remove their crops from the structure and apply a broad-spectrum POST product, or pay for the labor to manually hand-weed. Indaziflam is unique compared with other herbicides because it has a low volatility index, which could potentially expand its use in greenhouses during production. The objective of this study was to evaluate indaziflam as a PRE herbicide for use in greenhouses currently in production.

Materials and Methods

Two similar but separate experiments were conducted at the Paterson Greenhouse Complex in Auburn, AL. The following procedures apply to both experiments: Fifteen ground beds measuring 8.4 m^2 (90 ft^2) by 35.6 cm (14 in) deep with metal support walls and a gravel floor were used as the experimental site. Mini-greenhouses (MG) [2.4 by 2.4 m (8 by 8 ft) by 1.2 m (3.8 ft) tall] were constructed of 1.3 cm (0.5 in) PVC pipe and covered with Klerk's K-1 white 70% co-poly plastic (Klerks Hyplast Inc., Chester, SC 29706). Mini-greenhouses were constructed as a dome structure, containing no bottom so that the MG could be placed on top of the plants in the gravel ground beds, simulating a standard greenhouse environment. Five MGs were randomly selected to contain a window made of clear plastic and contained thermometers in order to monitor daily temperatures throughout the study.

Indaziflam (Marengo® SC, Bayer Environmental Science, Research Triangle Park, NC 27709) was applied at two rates including the manufacturer's labeled rate [40 g $ai{\cdot}ha^{-1}$ (0.04 lb $ai{\cdot}A^{-1}$)] (1×) and at twice the labeled rate [80 g $ai{\cdot}ha^{-1}$ (0.07 lb $ai{\cdot}A^{-1}$)] (2×). Each rate was applied using one of three different methods: 1) applied to only the gravel in ground beds with plants placed on gravel and covered with a MG immediately following application; 2) applied over the top of plants on gravel inside the ground beds and covered with MG immediately application; and 3) applied over the top of plants outside the ground beds on adjacent gravel and left outside of MG. Two nontreated control treatments were maintained for each species and were placed either on nontreated gravel inside ground beds and covered with a MG or outside ground beds on adjacent nontreated gravel and not covered with MG.

Indaziflam was applied using a CO_2-backpack sprayer fitted with an 8004 flat fan nozzle (TeeJet Technologies, Wheaton, IL 60187) at 172.4 kPa (25 psi) calibrated to deliver an application volume of 187 $L{\cdot}ha^{-1}$ (20 gpa). Treatments applied in ground beds were covered with the MG immediately after application. All treatments were covered with shade cloth (30%) after application and plant placement. Plants inside ground beds that were covered with MG received irrigation via 2.5 gpm pop-up sprinklers [1.3 $cm{\cdot}day^{-1}$ (0.5 $in{\cdot}day^{-1}$)] that were placed inside MG. Plants outside ground beds received overhead irrigation [1.3 cm/day (0.5 in/day)] via overhead impact sprinklers. Mini-greenhouse covers were removed three days after application and plants were removed from ground beds and placed under the shade cloth (30%) structure and received overhead irrigation [1.3 $cm{\cdot}day^{-1}$ (0.5 $in{\cdot}day^{-1}$)] via overhead impact sprinklers for the remainder of the experiments. Data collected in both experiments included injury ratings on all species based on a 1 to 10 scale (1 = no injury and 10 = dead plant) at 3, 10, 24, and 30 days after treatment (DAT). Fresh weights (FW) were taken on all species at 30 DAT by cutting plant shoots at the soil line and immediately weighing the sample after harvesting. The experiment was designed as a complete randomize block and all data were analyzed using Duncan's Multiple Range Test (SAS® Institute version 9.2, Cary, NC). Data from experiments 1 and 2 were analyzed separately due to significant experiment by treatment interactions. In all cases, differences were considered significant at $p \leq 0.05$.

Experiment 1. 'Better Boy' tomato (288 count plug trays) and 'Dreams White' petunia were potted into 36 cell packs on May 17, 2011, using a pinebark:sand (6:1 v:v) media that had been amended with 8.31 $kg{\cdot}m^{-3}$ (14 $lbs{\cdot}yd^{-3}$) of Polyon (Harrell's Fertilizer, Inc., Lakeland, FL) control release fertilizer [15.0N-2.64P-9.96K (15-6-12)], 3.0 $kg{\cdot}m^{-3}$ (5 $lbs{\cdot}yd^{-3}$) dolomitic limestone, and 0.9 $kg{\cdot}m^{-3}$ (1.5 $lbs{\cdot}yd^{-3}$) Micromax (The Scott's Company, Marysville, OH) prior to potting. On May 31, 2011, 'Extreme Orange' impatiens were obtained in 10.2 cm (4 in) pots from a local supplier and were not transplanted. Each treatment consisted of three replications, with 15 sub-replications for tomato and petunia and 10 sub-

Table 1. **'Extreme Orange' impatiens injury ratings and fresh weights following indaziflam applications in greenhouse situations, Experiments 1 and 2.**

Application placement[w]	Rate[v]	Injury ratings[z] 3 DAT[y] EXP. 1	3 DAT EXP. 2	10 DAT EXP. 1	10 DAT EXP. 2	24 DAT EXP. 1	24 DAT EXP. 2	30 DAT EXP. 1	30 DAT EXP. 2	Shoot fresh weights (g)[x] EXP. 1	Shoot fresh weights (g) EXP. 2
G-MG	1×	1.0c[u]	1.0c	1.0c	1.0b	1.0b	1.0b	1.0b	1.0b	109.9a	15.9b
G-MG	2×	1.0c	1.0c	1.0c	1.0b	1.0b	1.0b	1.0b	1.0b	97.0ab	17.7a
OTT-MG	1×	3.7a	3.0a	4.0a	8.7a	9.3a	9.7a	9.7a	10.0a	0.1c	0.0d
OTT-MG	2×	2.7b	3.0a	4.0a	9.0a	9.3a	10.0a	9.7a	10.0a	1.3c	0.0d
OTT	1×	1.0c	2.0b	3.7a	8.3a	9.7a	9.7a	9.7a	10.0a	0.2c	0.0d
OTT	2×	1.0c	2.0b	3.0b	8.3a	10.0a	9.7a	10.0a	10.0a	0.0c	0.0d
C	NA	1.2c	1.0c	1.0c	1.0b	1.0b	1.0b	1.0b	1.0b	96.0b	16.0ab
OC	NA	1.0c	1.0c	1.0c	1.0b	1.0b	1.0b	1.0b	1.0b	112.2a	13.8c

[z]Injury ratings based on a scale of 1 to 10, 1 = no injury, 10 = dead plant.

[y]DAT = days after treatment.

[x]Shoot fresh weights were taken at 30 DAT for each experiment and are presented in grams.

[w]G-MG = herbicide applied to gravel with plants placed on gravel inside mini-greenhouses immediately following application; OTT-MG = herbicide applied over the top of plants on gravel ground beds and then placed inside mini-greenhouses immediately following application; OTT = plants treated over the top and not placed inside mini-greenhouses; C = nontreated control placed in gravel ground beds inside mini-greenhouses; OC = nontreated control placed outside of gravel ground beds and not placed inside mini-greenhouses.

[v]1× = 40 g ai·ha–1 (0.04 lbs ai·A^{-1}); 2× = 80 g ai·ha^{-1} (0.07 lbs ai·A^{-1}).

[u]Means within column followed by the same letter are not significantly different based on Duncan's Multiple Range Test (p = < 0.05).

replications for impatiens. On June 7, 2011 [clear, 28 C (83 F), 61% relative humidity, winds E at 7 mph) treatments were applied as previously described.

Experiment 2. 'Dreams Neon Rose' petunia were transplanted from plug trays (200 count) into 36 cell packs on May 15 and 18, 2012, using potting media as described above. Better Boy tomatoes (288 count plug trays) were potted into 36 cell packs on May 15 and 21, 2012. Each treatment was replicated three times for each species, with 24 sub-replications. All species were blocked by plant size and by potting date prior to herbicide application. On June 12, 2012 [mostly cloudy, 24 C (75 F), 73% relative humidity, winds WNW at 5 mph) treatments were applied as previously described.

Results and Discussion

Experiment 1. Impatiens placed on indaziflam-treated gravel at either rate (rating of 1.0) and covered with MG had similar injury ratings to both nontreated control treatments (both inside MG and outside MG) throughout the study (Table 1). Slight injury was observed on impatiens in the control treatment covered with MG at 3 DAT (1.2) which was likely due to the high temperatures reached inside the MG during the three days they were in place [38 C (100 F) on June 7, 42 C (108 F) on June 8, and 40 C (104 F) on June 9, 2011]. However, this injury quickly dissipated and no further injury was observed at 10, 24, or 30 DAT. Impatiens treated over the top and then covered with MG began to show signs of injury at 3 DAT (injury ratings of 3.7 and 2.7 at the 1 and 2× rates, respectively). While no injury was observed on impatiens treated over-the-top at 3 DAT but not covered with MG, injury ratings steadily increased throughout the study. Impatiens treated with either over-the-top treatment (inside or outside of MG) were severely injured or completely dead by 30 DAT, regardless of herbicide rate. Impatiens FW also indicated that both over-the-top treatments caused severe injury or killed plants, while impatiens placed on indaziflam-treated gravel and then covered with MG had FW similar to the nontreated control treatments.

Dreams White petunias placed on indaziflam-treated gravel (both rates) and covered with MG had similar injury ratings to both control treatments throughout the study (Table 2). While injury was observed in the petunias placed on indaziflam-treated gravel inside MG at times, particularly at 10 DAT (injury ratings of 3.3 and 2.0 at the 1 and 2× rates, respectively), this was likely due to the high temperatures recorded inside the MG during experiment 1. Petunias treated over the top and covered with MG had higher injury ratings than any other treatment at 3 DAT (3.0 and 3.3 at the 1 and 2× rates, respectively) and both petunias treated with either of the over-the-top treatments (inside or outside of MG) had higher injury ratings than any other treatment at 24 DAT at both rates. By 30 DAT, petunias treated over the top and covered with MG (5.7) and over the top outside of the MG (5.7) at the 2× rate had higher injury ratings than any other treatment, followed by the over-the-top treatment covered with MG (4.0) and the over-the-top treatment outside of MG (4.3) at the 1× rate. Petunia FW in experiment 1 were similar to FW observed in impatiens as petunias placed on treated gravel and covered with MG had similar FW to nontreated control treatments and petunias treated with either of the over-the-top treatments were significantly smaller than petunias in other treatments (Table 2).

Better Boy tomato injury ratings were similar to those observed in petunia. Tomatoes placed on indaziflam-treated gravel and covered with MG had similar injury ratings to both control treatments throughout the study (Table 3). Tomato FW also showed that tomatoes placed on treated gravel and covered with MG (either rate) were similar in size to nontreated control plants at the conclusion of experiment 1. Tomatoes treated over-the-top and covered with MG had higher injury ratings than any other treatment at 3 DAT (3.0 and 3.3 at the 1 and 2× rates, respectively). By 24 DAT,

Table 2. 'Dreams White' (Experiment 1) and Dreams Rose petunia (Experiment 2) injury ratings and fresh weights following indaziflam applications in greenhouse situations.

Application placement[w]	Rate[v]	Injury ratings[z]								Shoot fresh weights (g)[x]	
		3 DAT[y]		10 DAT		24 DAT		30 DAT			
		EXP. 1	EXP. 2	EXP. 1	EXP. 2	EXP. 1	EXP. 2	EXP. 1	EXP. 2	EXP. 1	EXP. 2
G-MG	1×	1.0b[u]	1.0b	3.3abc	1.0b	2.3b	1.0c	1.7c	1.0d	16.3a	7.0c
G-MG	2×	1.3b	1.0b	2.0bc	1.0b	2.0b	1.0c	1.7c	1.0d	16.3a	12.2a
OTT-MG	1×	3.0a	2.3a	3.7ab	6.0a	5.3a	5.7b	4.0b	4.3c	7.4b	4.3d
OTT-MG	2×	3.3a	2.3a	4.0a	7.3a	6.7a	7.7a	5.7a	8.0a	2.0b	1.0e
OTT	1×	1.3b	2.0a	3.3abc	6.7a	5.7a	5.7b	4.3b	6.7b	7.0b	2.3e
OTT	2×	1.3b	2.0a	3.0abc	6.3a	5.7a	7.3a	5.7a	7.7ab	3.0b	1.3e
C	NA	1.0b	1.0b	1.7c	1.0b	1.0b	1.0c	1.3c	1.0d	22.9a	9.8b
OC	NA	1.0b	1.0b	1.3c	1.0b	1.0b	1.0c	1.0c	1.0d	19.5a	8.8bc

[z]Injury ratings based on a scale of 1 to 10, 1 = no injury, 10 = dead plant.

[y]DAT = days after treatment.

[x]Shoot fresh weights were taken at 30 DAT for each experiment and are presented in grams. Shoot fresh weights for Dreams White petunia are shown for experiment 2 and shoot fresh weights for Dreams Rose petunia are shown for Experiment 2.

[w]G-MG = herbicide applied to gravel with plants placed on gravel inside mini-greenhouses immediately following application; OTT-MG = herbicide applied over the top of plants on gravel ground beds and then placed inside mini-greenhouses immediately following application; OTT = plants treated over the top and not placed inside mini-greenhouses; C = nontreated control placed in gravel ground beds inside mini-greenhouses; OC = nontreated control placed outside of gravel ground beds and not placed inside mini-greenhouses.

[v]1× = 40 g ai·ha^{-1} (0.04 lbs ai·A^{-1}); 2× = 80 g ai·ha^{-1} (0.07 lbs ai·A^{-1}).

[u]Means within column followed by the same letter are not significantly different based on Duncan's Multiple Range Test ($p = \leq 0.05$).

tomatoes treated with either over-the-top application had higher injury ratings than any other treatment. By 30 DAT, tomato injury was similar to injury observed in petunias in that tomatoes treated over the top and covered with MG (5.7) and over the top and left outside MG (5.7) at the 2× rate had higher injury ratings than any other treatment, followed by the same treatments at the 1× rate. While tomato mean injury ratings never exceeded 6.7 (those treated over the top and covered with MG at 2× rate at 24 DAT), FW data shows that none of the tomatoes treated over the top were marketable as mean FW ranged from 0.0 to 0.2 for all over-the-top treatments (Table 3).

Experiment 2. Impatiens treated over the top and covered with MG (injury rating of 3.0 at both rates) had the highest injury ratings of any treatment followed by the over-the-top treatment outside MG (injury rating of 2.0 at both rates). Similar to experiment 1, no injury was observed on impatiens placed on indaziflam-treated gravel and covered with MG throughout the study, regardless of herbicide rate. Fresh weights also indicate that impatiens placed on indaziflam-treated gravel and covered with MG were similar in size or larger than the nontreated control plants at 30 DAT (Table 1). By 10 DAT, impatiens injury ratings in over-the-top treatments but not covered (8.3 at both rates) were similar

Table 3. 'Better Boy' tomato injury ratings and fresh weights following indaziflam applications in greenhouse situations, Experiments 1 and 2.

Application placement[w]	Rate[v]	Injury ratings[z]								Shoot fresh weights (g)[x]	
		3 DAT[y]		10 DAT		24 DAT		30 DAT			
		EXP. 1	EXP. 2	EXP. 1	EXP. 2	EXP. 1	EXP. 2	EXP. 1	EXP. 2	EXP. 1	EXP. 2
G-MG	1×	1.0b[u]	1.0b	3.3abc	1.0b	2.3b	1.0b	1.7c	1.0b	27.0a	8.6b
G-MG	2×	1.3b	1.0b	2.0bc	1.0b	2.0b	1.0b	1.7c	1.0b	26.4a	9.3ab
OTT-MG	1×	3.0a	2.7a	3.7ab	8.3a	5.3a	10.0a	4.0b	10.0a	0.0b	0.0c
OTT-MG	2×	3.3a	3.0a	4.0a	8.7a	6.7a	10.0a	5.7a	10.0a	0.0b	0.0c
OTT	1×	1.3b	2.3a	3.3abc	8.7a	5.7a	10.0a	4.3b	10.0a	0.2b	0.0c
OTT	2×	1.3b	2.3a	3.0abc	8.7a	5.7a	10.0a	5.7a	10.0a	0.0b	0.0c
C	NA	1.0b	1.0b	1.7c	1.0b	1.0b	1.0b	1.3c	1.0b	28.8a	10.1a
OC	NA	1.0b	1.0b	1.3c	1.0b	1.0b	1.0b	1.0c	1.0b	32.0a	8.7b

[z]Injury ratings based on a scale of 1 to 10, 1 = no injury, 10 = dead plant.

[y]DAT = days after treatment.

[x]Shoot fresh weights were taken at 30 DAT for each experiment and are presented in grams.

[w]G-MG = herbicide applied to gravel with plants placed on gravel inside mini-greenhouses immediately following application; OTT-MG =herbicide applied over-the-top of plants on gravel ground beds and then placed inside mini-greenhouses immediately following application; OTT = plants treated over-the-top and not placed inside mini-greenhouses; C = nontreated control placed in gravel ground beds inside mini-greenhouses; OC = nontreated control placed outside of gravel ground beds and not placed inside mini-greenhouses.

[v]1× = 40 g ai·ha^{-1} (0.04 lbs ai·ac^{-1}); 2×= 80 g ai·ha^{-1} (0.07 lbs ai·ac^{-1}).

[u]Means within column followed by the same letter are not significantly different based on Duncan's Multiple Range Test ($p = < 0.05$).

to injury ratings observed in over-the-top treatments placed inside MG (8.7 and 9.0 at the 1 and 2× rates, respectively). Similar results were observed in these treatments at 24 DAT, and by 30 DAT all impatiens receiving either over-the-top treatment were completely dead (injury ratings of 10.0). All impatiens receiving an over-the-top application had a mean FW of 0.0.

Dreams Rose petunias placed on indaziflam-treated gravel and covered with MG showed no signs of injury throughout the study (Table 2). The only difference observed between petunias placed on indaziflam-treated gravel and covered with MG and the control groups was that petunias on treated gravel inside MG at the 1× rate were smaller than petunias in the nontreated control group inside MG. The difference in FW for petunias placed on treated gravel at the 1× rate is unclear, but was likely due to environmental factors and not due to herbicide volatility as petunias treated at the 2× rate were had higher FW than either control treatment. Neither control treatment had any injury throughout the experiment, likely due to slightly cooler temperatures than that observed inside the MGs during experiment 2 [high temperatures of 37 C (98 F) on June 6, 34 C (94 F) on June 7, and 39 C (102 F) on June 8, 2012]. By 10 DAT, petunias treated with either over-the-top treatment had higher injury ratings than any other treatment. At 24 and 30 DAT, over-the-top treatments had higher injury than other treatments, with injury generally increasing with herbicide rate.

Similar to results observed in petunias, tomatoes placed on treated gravel and covered with MG showed no signs of injury throughout the study and had similar injury ratings to both nontreated controls on all evaluation dates (Table 3). Fresh weights show that tomatoes placed on treated gravel and covered with MG at 1× (8.6 g) were smaller than tomatoes with no herbicide treatment and covered with MG (10.1 g) (Table 3). Again, similar to results seen in petunias, tomatoes placed on treated gravel at the 2× rate and covered with MG were similar in size to both nontreated control groups. Tomatoes treated with either over-the-top application had higher injury ratings than any other treatment and injury ratings increased on each evaluation date. By 24 DAT, all tomatoes receiving an over-the-top application were completely dead and all over-the-top applications had mean FWs of 0.0 at 30 DAT.

In both experiments, minimal injury was observed when plants were placed on indaziflam-treated gravel and covered with a MG regardless of herbicide rate or species in experiment 1 and no injury was observed in plants placed on treated gravel and covered with MG in experiment 2. Fresh weight data also show that impatiens, petunias, and tomatoes placed on treated gravel and covered with a MG had similar FW to the nontreated control groups in most cases. While plant injury did occur in experiment 1, injury ratings never exceeded 3.3 (Dreams White petunia and Better Boy tomato at 10 DAT) and was possibly due to the extreme temperatures reached inside the MG during experiment 1, as the nontreated petunias and tomatoes placed inside MG also showed some injury at this date. Impatiens placed on treated gravel and covered with MG had fully recovered in experiments 1 (injury ratings of 1.0 at both rates), and while petunias and tomatoes still had minimal injury symptoms at 30 DAT in experiment 1 (ratings of 1.7 at both rates in both species), these plants would still have been considered marketable. All species had fully recovered after being placed on treated gravel and covered with MG by 30 DAT in experiment 2 (mean injury ratings of 1.0 at both rates in all species).

Significant injury was observed when plants received either over-the-top application in both experiments, regardless of whether plants were placed inside the MG after the herbicide was applied or not. Impatiens treated over-the-top where either dead or almost dead by 24 DAT in experiment 1, and completely dead by 30 DAT during experiment 2. Tomatoes showed similar injury to that observed in impatiens during experiment 2, and while petunias generally had lower injury ratings than impatiens or tomatoes when treated over-the-top, none of these petunias would have been considered marketable. Fresh weights taken in both experiments further illustrate that none of the species evaluated were tolerant of over-the-top applications of indaziflam at either rate tested.

Results from this trial indicate that indaziflam will likely cause little to no plant phytotoxicity due to volatility and could likely be applied safely to gravel in greenhouses while the ornamentals evaluated in this study are present and in production. Our experiments were conducted in MG under a worst-case scenario with air temperatures rising up to 42 C (108 F) in experiment 1 and 39 C (102 F) in experiment 2. Plants had no ventilation after treatment for 3 days in either experiment. Our study determined that under these extreme environmental conditions, when only the gravel was sprayed with indaziflam, plants had little to no injury, while plants receiving over-the-top treatments had severe injury by 30 DAT or sooner, and would not have been marketable. When applying indaziflam SC around ornamentals, applicators should take great care in order to avoid making any contact with plant foliage with the herbicide as injury could occur on sensitive species. It is important to note that the current indaziflam (Marengo®) label (Anonymous 2014) restricts applications inside enclosed structures to times when greenhouses are empty, a precaution that currently must be followed by all applicators to avoid other potential scenarios that may result in plant phytotoxicity. In trials by Senesac (2015), indaziflam was applied to three different areas of an enclosed hoophouse covered with polyethylene film including 1) 0.6 m (2 ft) swath along the floor; 2) 0.6 m (2 ft) swath applied along the vertical wall starting where the wall and the floor intersect; and 3) 0.6 m (2 ft) swath applied 1.2 m (4 ft) up on the vertical curve of the hoop house wall. Bedding and vegetable plants (coleus [*Solenostemon scutellarioides* (L.) Codd], petunia, portulaca (*Portulaca* spp.), parsley [*Petroselinum crispum* (Mill.) Nyman ex A.W. Hill] and tomato) were then placed inside beneath the three spray zones and hand watered to evaluate if plants would be injured from a 'splash back' effect from indaziflam being washed off of greenhouse structures. Results showed that coleus and portulaca were the most sensitive species to indaziflam, but injury never exceeded 18% for any species. While results of Senesac (2015) showed minimal impact from a 'splash back' effect from indaziflam applied on greenhouse walls or plastic, other species could potentially be much more sensitive, and higher rates or different plant placements could potentially result in significant phytotoxicity due to poor application practices. However, results from our trial show that indaziflam will likely cause little to no injury to the plants mentioned in this trial as a result of volatility when applied inside an enclosed structure, even in cases where plants were immediately reintroduced after treatment, but applicators should still use caution to avoid other situations which may result in phytotoxicity (Senesac, 2015). While additional research is needed on other plant species, preliminary results suggest that indaziflam could potentially be applied as a preemergence herbicide inside enclosed structures during production.

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