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Weed Management–Other Crops/Areas

Application Placement Affects Postemergence Smooth Crabgrass (*Digitaria ischaemum*) and Annual Bluegrass (*Poa annua*) Control with Indaziflam

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Greenhouse experiments were conducted to determine the effects of herbicide placement on POST smooth crabgrass and annual bluegrass control. Soil-plus-foliar, soil-only, and foliar-only applications of indaziflam (52.5 g ai ha^{-1}), dithiopyr (560 ai g ha^{-1}), or quinclorac (840 g ai ha^{-1}) were made to one-tiller smooth crabgrass plants. Similarly, indaziflam (52.5 g ha^{-1}), foramsulfuron (29 g ai ha^{-1}), or prodiamine (840 g ai ha^{-1}) were applied to nontillering annual bluegrass plants in an identical manner. No differences in smooth crabgrass control were detected between soil-plus-foliar and soil-only applied indaziflam from 21 to 35 d after treatment (DAT). By 28 DAT, smooth crabgrass control and biomass reductions with these indaziflam treatments were $\geq$ 90% and not different than quinclorac. Comparatively, smooth crabgrass control with foliar-only applications of indaziflam never exceeded 28%. Responses on annual bluegrass were similar as soil-plus-foliar and soil-only applied indaziflam exhibited greater efficacy than indaziflam applied foliar-only. By 28 DAT, annual bluegrass control and aboveground biomass reductions with soil-plus-foliar and soil-only treatments were $\geq$ 86% and not different from foramsulfuron. Comparatively, foliar-only applications of indaziflam controlled annual bluegrass $\leq$ 2%. These results indicate that root absorption is required for POST control of smooth crabgrass and annual bluegrass with indaziflam. Further research is needed to determine if techniques to enhance indaziflam contact with soil will enhance POST smooth crabgrass and annual bluegrass control in the field.

Nomencalture: Dithiopyr; indaziflam; foramsulfuron; prodiamine; quinclorac; annual bluegrass, *Poa annua* L.; smooth crabgrass, *Digitaria ischaemum* (Schreb.) Schreb. ex Muhl.

Key words: Foliar-only; soil-only; soil-plus-foliar; turf; turfgrass; weed control.

Se realizaron experimentos de invernadero para determinar los efectos de la localización de herbicidas en el control POST de *Digitaria ischaemum* y *Poa annua*. Aplicaciones al suelo-más-foliar, solamente-suelo y solamente-foliar de indaziflam (52 g ai ha^{-1}), dithiopyr (560 g ai ha^{-1}) o quinclorac (840 g ai ha^{-1}) fueron realizadas en plantas de *D. ischaemum* en estado de un hijuelo. Similarmente, indaziflam (52 g ai ha^{-1}), foramsulfuron (29 g ai ha^{-1}) o prodiamine (840 g ai ha^{-1}) fueron aplicadas a plantas de *P. annua* sin hijuelos en forma idéntica. No se detectaron diferencias en el control de *D. ischaemum* entre suelo-más-foliar y solamente-suelo con indaziflam entre 21 y 35 d después del tratamiento (DAT). A 28 DAT, el control y la reducción de biomasa con estos tratamientos con indaziflam fueron $\geq$90% y no fueron diferentes del quinclorac. Comparativamente, el control de *D. ischaemum* con aplicaciones solamente-foliar de indaziflam nunca excedió 28%. Las respuestas de *P. annua* fueron similares, en tanto que las aplicaciones suelo-más-foliar y solamente-suelo de indaziflam exhibieron mayor eficacia que indaziflam aplicado solamente-foliar. A 28 DAT, el control y la reducción de biomasa aérea de *P. annua* con tratamientos suelo-más-foliar y solamente-suelo fueron $\geq$86% y no fueron diferentes al foramsulfuron. Comparativamente, aplicaciones solamente-foliar de indaziflam controlaron *P. annua* $\leq$2%. Estos resultados indican que se requiere absorción radicular para el control POST de *D. ischaemum* y *P. annua* con indaziflam. Se necesita investigación adicional para determinar si técnicas para mejorar el contacto de indaziflam con el suelo incrementarán el control en campo de *D. ischaemum* y *P. annua*.

Smooth crabgrass and annual bluegrass are grassy weeds that commonly infest golf course, athletic field, and landscape turf (McCarty et al. 2005). Smooth crabgrass and annual bluegrass color, leaf texture, seedhead production, and stress tolerance reduce turfgrass aesthetic and functional quality.

Indaziflam is an alkylazine herbicide that controls annual weeds at rates of 35 to 70 g ai ha^{-1} by inhibiting cellulose biosynthesis in susceptible species (Myers et al. 2009). Brosnan et al. (2011) reported that PRE applications of indaziflam at 35, 52.5, and 70 g ha^{-1} controlled smooth crabgrass similar to prodiamine at 840 g ai ha^{-1}. Indaziflam at 35 g ha^{-1} has also been shown to provide POST control of nontillered smooth crabgrass similar to dithiopyr at 560 g ha^{-1} and quinclorac at 840 g ha^{-1} (J. T. Brosnan, unpublished data). Effective PRE control of annual bluegrass with indaziflam has been reported at rates of 30 to 60 g ha^{-1} (Brosnan et al. 2012; Perry et al. 2011a). Indaziflam efficacy for POST annual bluegrass control has also been observed (Brosnan et al. 2012). The researchers observed 88 to 100% control with applications at 35 and 52.5 g ha^{-1} made 4 wk after a standard PRE timing. However, reduced efficacy was observed with applications made 8 and 12 wk after a standard PRE timing. Brosnan et al. (2012) suggested that plant size, maturity, and environmental conditions at application may affect POST control with indaziflam.

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Application placement has been shown to affect herbicide efficacy for POST control of annual grassy weeds in managed turfgrass systems. Perry et al. (2011b) observed greater annual bluegrass control with soil-only and soil-plus-foliar applications of amicarbazone compared to applications made only to foliage. McCurdy et al. (2009) reported large crabgrass [*Digitaria sanguinalis* (L.) Scop.] and yellow nutsedge (*Cyperus esculentus* L.) control was similar for soil-only and foliar-only applications of mesotrione at 0.14 and 0.28 kg ai ha^{-1} when evaluated 56 d after treatment (DAT). The researchers concluded that turfgrass managers should consider granular or high carrier volume applications to improve mesotrione efficacy. Gannon et al. (2012) reported that soil-only and soil-plus-foliar applications of sulfentrazone, sulfosulfuron, and trifloxysulfuron resulted in better control of yellow nutsedge, purple nutsedge (*Cyperus rotundus* L.), and false green kyllinga (*Kyllinga gracillima* Miq.) than foliar-only applications.

In a study evaluating smooth crabgrass control with mesotrione, Goddard et al. (2010) reported an interaction between application placement and relative humidity. The researchers observed greater smooth crabgrass control under conditions of 50% relative humidity with soil-only and soil-plus-foliar applications of mesotrione compared to those made to only foliage. However, when treatments were applied at 90% relative humidity, smooth crabgrass control with foliar-only applications increased by 55 to 66% from 7 to 21 DAT and was not different from that achieved with soil-only applications by 21 DAT. Goddard et al. (2010) observed that mesotrione symptoms (i.e., bleaching) were apparent in the youngest leaves following soil-only and soil-plus-foliar applications, while foliar-only treatments resulted in symptoms developing in older leaf tissue. The researchers surmised that mesotrione application placement affected translocation in smooth crabgrass.

Previous research with other POST herbicides illustrated that application placement can affect efficacy for POST control of annual grassy weeds (Goddard et al. 2010; McCurdy et al. 2009; Perry et al. 2011b). However, data describing the effect of application placement on POST annual grass control with indaziflam are limited. Therefore, the objective of this research was to evaluate POST smooth crabgrass and annual bluegrass control with soil-only, soil-plus-foliar, and foliar-only applications of indaziflam.

Materials and Methods

Plant Culture. Greenhouse experiments were conducted at the University of Tennessee (Knoxville, TN) from November 2011 to February 2012. During these experiments, day/night temperatures in the greenhouse averaged 27/15 C. Peak light intensity ranged from 281 to 654 $\mu mol\ m^{-2}\ s^{-1}$ and averaged 455 $\mu mol\ m^{-2}\ s^{-1}$. Natural light conditions were supplemented with 1,000 W high-pressure sodium lamps (PL 2000, PL Light, Beamsville, ON) for a duration of 18.5 h each day. Smooth crabgrass (Herbiseed, New Farm Mire Lane, Twyford, England) and annual bluegrass (Penn State University, Valentine Turfgrass Research Center, University Park, PA) were surface seeded into 10-cm-diam pots filled with a Sequatchie loam soil (fine-loamy, siliceous, semiactive, thermic humic Hapludult) with a pH of 6.1, 1.4% organic matter, and a cation exchange capacity of 10.1 mEq 100 g^{-1}. Plants were irrigated with an overhead misting system as needed to maximize growth and vigor.

Smooth Crabgrass Experiments. Plants were allowed to grow in the greenhouse environment for 4 wk prior to initiating smooth crabgrass experiments. Prior to treatment application the plant canopy was thinned such that each pot contained three one-tiller smooth crabgrass plants averaging 4 cm in height. Treatments included the factorial combination of three herbicides and application placements. Herbicides included indaziflam (Specticle 20 WSP, Bayer Environmental Sciences, Research Triangle Park, NC) at 52.5 g ha^{-1}, dithiopyr (Dimension 2EW, Dow AgroSciences, Indianapolis, IN) at 560 g ha^{-1}, and quinclorac (Drive XLR8, BASF Corporation, Research Triangle Park, NC) at 840 g ha^{-1} plus a methylated seed oil surfactant at 0.6% v/v. Application placements included soil-only, soil-plus-foliar, and foliar-only. A nontreated check was included for comparison.

Annual Bluegrass Experiments. Plants were allowed to grow in the greenhouse environment for 4 wk prior to initiating annual bluegrass experiments. Prior to treatment application the plant canopy was thinned such that pots contained 10 nontillered annual bluegrass plants averaging 5.5 cm in height. Treatments included the factorial combination of three herbicides and three application placements. Herbicides included indaziflam at 52.5 g ha^{-1}, prodiamine (Barricade 65WG, Syngenta Professional Products, Greensboro, NC) at 840 g ha^{-1}, and foramsulfuron (Revolver, Bayer Environmental Sciences) at 29 g ha^{-1}. Prodiamine was included in this research as current labeling compares similarly to indaziflam (Anonymous 2010b, 2010c). Application placements included soil-only, soil-plus-foliar, and foliar-only. A nontreated check was included for comparison.

Treatment Application. Soil-plus-foliar and foliar-only treatments were applied using a CO_2-powered boom sprayer calibrated to deliver 281 L ha^{-1} of water carrier using 8002 flat-fan nozzles (Teejet flat fan spray nozzles, Wheaton, IL). For foliar-only treatments, a 2-cm-thick layer of cotton roll (Fisher Scientific, Hanover Park, IL) was placed on the surface of each pot to prevent herbicides from contacting soil. Soil-only treatments were applied by diluting each rate of herbicide in 10 ml of water and syringing this solution onto the soil surface without contacting plant foliage. Pots were allowed to dry for a minimum of 30 min before removing the cotton roll. Irrigation was withheld for a minimum of 48 h after herbicide application as well.

Data Collected. Smooth crabgrass control was visually assessed on a percent scale relative to the nontreated check, where 0 equaled no control and 100 equaled complete plant death. Assessments of smooth crabgrass control were made at 7, 14, 21, 28, and 35 DAT. Annual bluegrass control was evaluated in the same manner until 28 DAT. Aboveground biomass data were also collected to provide a quantitative measure of smooth crabgrass and annual bluegrass control. After final visual assessments of control were made,

Table 1. Effects of herbicide placement on smooth crabgrass control and aboveground biomass in two combined greenhouse experiments.

Placement	Herbicide	Rate	Smooth crabgrass control					Aboveground biomass
			7 DAT[a]	14 DAT	21 DAT	28 DAT	35 DAT	
		$g\ ai\ ha^{-1}$	%					% reduction
Soil-plus-foliar	Dithiopyr	560	4	28	58	76	80	91
	Indaziflam	52.5	47	68	87	95	93	98
	Quinclorac[b]	840	89	100	100	100	98	99
Soil-only	Dithiopyr	560	2	8	37	45	43	67
	Indaziflam	52.5	18	43	76	90	84	95
	Quinclorac	840	71	99	100	100	98	98
Foliar-only	Dithiopyr	560	2	9	33	17	8	66
	Indaziflam	52.5	5	22	28	18	6	67
	Quinclorac	840	90	98	99	100	98	99
$LSD_{0.05}$			17	14	16	21	17	21

[a] Abbreviation: DAT, days after treatment.

[b] All quinclorac treatments applied with a methylated seed oil surfactant at 0.6 % v/v.

aboveground biomass from each pot was removed at the soil line, dried at 105 C for 48 h, and weighed. Aboveground biomass data are presented as a percent reduction compared to the nontreated check.

Statistical Analysis. Smooth crabgrass and annual bluegrass responses were assessed in separate experiments, each arranged as a 3 by 3 factorial, randomized complete block, with three replications. Two runs of each experiment were conducted. Data from each were subjected to ANOVA in SAS software (SAS Institute Inc., 100 SAS Campus Drive, Cary, NC 27513-2414) using the appropriate expected mean square values described by McIntosh (1983). Fisher's protected LSD values were calculated when the *F* ratio was significant at the 0.05 level. No significant experimental run-by-treatment interactions were detected; thus, data from each run were combined.

Results and Discussion

Smooth Crabgrass Control. Significant herbicide-by-application placement interactions were detected in smooth crabgrass control and aboveground biomass data (Table 1). Soil-plus-foliar applications of indaziflam controlled smooth crabgrass greater than treatments applied soil-only or foliar-only 7 and 14 DAT. However, no differences in smooth crabgrass control were detected between soil-plus-foliar and soil-only applications of indaziflam from 21 to 35 DAT. Smooth crabgrass control with these treatments ranged from 76 to 95% and was not different from quinclorac 28 and 35 DAT. Foliar-only applications of indaziflam controlled smooth crabgrass less than soil-only and soil-plus-foliar applications from 14 to 35 DAT and never exceeded 28% on any evaluation date. Aboveground biomass data supported visual assessments of smooth crabgrass control as soil-plus-foliar and soil-only applications of indaziflam reduced aboveground biomass $\geq$ 95% compared to only 67% for indaziflam applied foliar-only.

Soil-plus-foliar applications of dithiopyr controlled smooth crabgrass greater than treatments applied soil-only or foliar-only from 14 to 35 DAT. No differences were detected between soil- and foliar-only applications of dithiopyr from 7 to 21 DAT. At 28 and 35 DAT, soil-only dithiopyr applications controlled smooth crabgrass greater than those applied foliar-only; however, reductions in aboveground biomass with these treatments were not significantly different from one another. Aboveground biomass reductions with soil-plus-foliar applications of dithiopyr were greater than treatments applied soil-only or foliar-only. Others have found that dithiopyr is absorbed primarily by roots and to a smaller degree in the foliage of susceptible species (Senseman 2007). However, Keeley et al. (1997) observed similar large crabgrass control with soil-plus-foliar and foliar-only applications of dithiopyr at rates ranging from 10 to 70 g ha^{-1}. It was concluded that the primary site of dithiopyr POST uptake was plant foliage because foliar-only applications provided similar control to those applied soil-only at the 40 and 70 g ha^{-1} rates. Differences between studies could be attributed to the dithiopyr rate used. In our research, dithiopyr was applied at 560 g ha^{-1} compared to rates $\leq$ 70 g ha^{-1} in the work of Keeley et al. (1997). The 560 g ha^{-1} rate selection was based on the dithiopyr label for smooth crabgrass control and previous research in Tennessee and Georgia (Anonymous 2010a; Brosnan et al. 2010). Soil-plus-foliar and foliar-only applications of dithiopyr controlled smooth crabgrass similar to indaziflam 35 DAT. However when applied soil-only, smooth crabgrass control with dithiopyr was less than indaziflam.

Quinclorac efficacy for smooth crabgrass control was not affected by application placement as control with soil-only, soil-plus-foliar, and foliar-only treatments measured $\geq$ 98% on all rating dates and resulted in $\geq$ 98% reductions in aboveground biomass. These responses illustrate that quinclorac can be absorbed by both root and leaf tissue of susceptible species and translocated in both xylem and phloem as discussed by Grossmann (1998). Soil-only and soil-plus-foliar applications of quinclorac and indaziflam controlled smooth crabgrass similarly 28 and 35 DAT. However, when these herbicides were applied foliar-only, quinclorac controlled smooth crabgrass greater than indaziflam on all evaluation dates. Responses in the current study differ from those of Williams et al. (2004) who reported foliar-only and soil-plus-foliar applications of quinclorac reduced torpedograss (*Panicum repens* L.) biomass greater than treatments

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Table 2. Effects of herbicide placement on annual bluegrass control and aboveground biomass in two combined greenhouse experiments.

Placement	Herbicide	Rate	Annual bluegrass control				Aboveground biomass
			7 DAT[a]	14 DAT	21 DAT	28 DAT	
		g ha^{-1}	%				% reduction
Soil-plus-foliar	Foramsulfuron	29	52	83	96	95	92
	Indaziflam	52.5	21	58	84	88	86
	Prodiamine	840	0	7	7	8	12
Soil-only	Foramsulfuron	29	37	63	79	78	88
	Indaziflam	52.5	40	72	90	90	90
	Prodiamine	840	0	0	0	0	14
Foliar-only	Foramsulfuron	29	55	83	93	93	93
	Indaziflam	52.5	2	2	2	0	29
	Prodiamine	840	7	5	0	0	20
$LSD_{0.05}$			14	13	10	12	23

[a] Abbreviation: DAT, days after treatment.

applied soil-only. However, reductions in torpedograss biomass measured ≤ 26% for all treatments. Differences between studies may be related to soil type as Williams et al. (2004) evaluated responses in a loamy sand (83% sand) with pH 5.7, while a silt loam (28% sand) with pH 6.1 was used in our research. Additionally, Williams et al. (2004) were working with a perennial species that persists from rhizomes, while data in the current study were generated using a diminutive (i.e., one-tiller) annual species.

Annual Bluegrass Control. Significant herbicide-by-application placement interactions were detected in annual bluegrass control and aboveground biomass data (Table 2). Soil-only applications of indaziflam controlled annual bluegrass greater than soil-plus-foliar and foliar-only applications 7 and 14 DAT. However, no differences in annual bluegrass control were detected between soil-plus-foliar and soil-only applications of indaziflam 21 to 28 DAT. Annual bluegrass control with these treatments ranged from 84 to 90% and was not different from foramsulfuron by 28 DAT. Foliar-only applications of indaziflam controlled annual bluegrass less than soil-only and soil-plus-foliar applications on all evaluation dates; annual bluegrass control with foliar-only applications of indaziflam never exceeded 2%. Aboveground biomass data supported visual assessments of annual bluegrass control as soil-plus-foliar and soil-only applications of indaziflam reduced aboveground biomass ≥ 86%. Foliar-only applications of indaziflam only reduced aboveground biomass 29%.

Prodiamine did not effectively control annual bluegrass in this study. Annual bluegrass control with prodiamine measured < 10% on all evaluation dates regardless of application placement. These responses support current prodiamine labeling for PRE control of annual bluegrass only (Anonymous 2010b). Prodiamine applications slightly regulated annual bluegrass growth as 12 to 20% reductions in aboveground biomass were reported with soil-plus-foliar, soil-only, and foliar-only applications.

Annual bluegrass control with foramsulfuron was affected by application placement. Soil-plus-foliar and foliar-only applications of foramsulfuron controlled annual bluegrass greater than soil-only applications on every evaluation date. Annual bluegrass control with soil-plus-foliar and foliar-only foramsulfuron applications was 83% by 14 DAT and ≥ 93% by 28 DAT. Comparatively, soil-only applications of foramsulfuron controlled annual bluegrass 63% at 14 DAT and 78% by 28 DAT. No differences in aboveground biomass were detected with soil-plus-foliar, foliar-only, and soil-only applications of foramsulfuron; all treatments reduced annual bluegrass biomass 88 to 93%.

These studies illustrate that application placement affects indaziflam efficacy for POST smooth crabgrass and annual bluegrass control. Soil-plus-foliar and soil-only applications resulted in greater control of both species than treatments applied foliar-only. These responses suggest that root absorption is required for POST control of smooth crabgrass and annual bluegrass with indaziflam. Further research is needed to determine if techniques to improve indaziflam contact with soil (i.e., increasing carrier volume, applications on a granular carrier, etc.) would enhance POST control of these species in the field.

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