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Effect of Selective Amicarbazone Placement on Annual Bluegrass (*Poa annua*) and Creeping Bentgrass Growth

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Growth chamber experiments were conducted to assess the effects of foliage-only, soil-only, and foliage-plus-soil placements of amicarbazone on annual bluegrass and creeping bentgrass growth. Evaluated herbicide treatments included amicarbazone at 49 or 147 g ai ha^{-1}, as well as bispyribac-sodium at 74 g ai ha^{-1} for comparative purposes. Data from this research agree with previous reports of amicarbazone plant uptake. Amicarbazone is absorbed via above- and belowground pathways; however, plant growth is inhibited more by root uptake. Compared to foliage-only amicarbazone placement, soil-only placement more than doubled reductions in aboveground biomass and root mass 56 d after treatment (DAT), whereas no differences were detected between placements including soil contact. Across all evaluated parameters in this research, amicarbazone (49 g ha^{-1}) impacted creeping bentgrass growth similarly to bispyribac-sodium, whereas annual bluegrass growth was inhibited more by amicarbazone, suggesting it provides a more efficacious chemical option for end-user applications.
Nomenclature: Amicarbazone; bispyribac-sodium; annual bluegrass, *Poa annua* L. var. *annua*; creeping bentgrass, *Agrostis stolonifera* L. 'Penn A1'.
Key words: Digital image analysis, foliar absorption, herbicide efficacy, herbicide placement, root absorption.

Se realizaron experimentos en cámaras de crecimiento para evaluar los efectos de aplicar amicarbazone solamente en el follaje, solamente en el suelo y en el follaje más el suelo, sobre el crecimiento de *Poa annua* y *Agrostis stolonifera*. Los tratamientos de herbicidas evaluados incluyeron amicarbazone a 49 ó 147 g ai ha^{-1}, y bispyribac-sodium a 74 g ai ha^{-1} para fines de comparación. Los datos de esta investigación concordaron con reportes previos sobre la absorción de amicarbazone, porque este compuesto es absorbido por vías por encima y debajo del suelo. Sin embargo, el crecimiento vegetal es inhibido más cuando la absorción se da por la raíz. Al compararse con la localización foliar del amicarbazone, la localización solamente en el suelo redujo la biomasa aérea y de raíz en más del doble a 56 días después del tratamiento (DAT), mientras que no se detectaron diferencias entre tratamientos que incluyeron contacto con el suelo. A lo largo de todos los parámetros evaluados en esta investigación, amicarbazone (49 g ha^{-1}) impactó el crecimiento de *A. stolonifera* en forma similar a bispyribac-sodium, mientras que el crecimiento de *P. annua* fue inhibido más por amicarbazone, lo que sugiere que este herbicida provee una opción química eficaz de control para los usuarios.

Annual bluegrass is a problematic cool-season weed that negatively impacts turfgrass aesthetics and functionality in warm- and cool-season turfgrass systems throughout the World. Indigenous to Europe, this weed is predominately propagated by seed and spread through human interaction (Beard 1970; Gaussoin 1990). When compared to properly managed creeping bentgrass systems, annual bluegrass is a lighter shade of green and is capable of producing abundant seedheads at golf course putting green mowing heights ($\approx$ 3 mm), leaving a mottled appearance and uneven playing surface (Christians 2011; Lush 1988). Further, annual bluegrass demonstrates poor heat and drought tolerance during summer conditions common to the transition, warm arid, and warm climatic zones of the United States (Beard 1970). This is problematic for putting green management because turfgrass quality is often decreased following stressful climatic conditions in areas infested with annual bluegrass due to turfgrass discoloration and coverage reduction (McCarty 2001).

Creeping bentgrass is the most widely used cool-season turfgrass species on golf course putting greens in the United States due to its fine texture, prostrate growth habit, and tolerance of low mowing heights ($\approx$ 3 mm) (Salaiz et al. 1995; Turgeon 1980). Native to Eurasia, creeping bentgrass is commonly used for all golf playing surfaces in cool-humid regions, but is predominately used on putting greens in warmer regions of the United States (Beard 1973). Creeping bentgrass has inherent difficulty growing in the southern reaches of its distribution in later summer months due to intensive mowing practices coupled with stressful environmental conditions, resulting in a weakened turfgrass stand susceptible to pest infestations (Beard and Daniel 1966; Carrow 1996). The timing of this scenario is of concern for preventing annual bluegrass establishment, because this weed produces readily viable seed that predominately germinate in the fall (Kaminski and Dernoeden 2007; Lush 1989; Shem-Tov and Fennimore 2003).

Amicarbazone is a photosystem II-inhibiting herbicide within the triazolinone family (Dayan et al. 2009; Senseman 2007). Symptoms produced on susceptible plants include chlorosis, stunted growth, tissue necrosis beginning at the leaf edges and progressing across and downward over leaf and stem tissue, and eventual death (Senseman 2007). In 2012, amicarbazone received registration in the United States for POST annual bluegrass control in creeping bentgrass golf course roughs, fairways, and tees (Anonymous 2012). Recent

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research suggests amicarbazone also has utility for annual bluegrass control in creeping bentgrass putting greens (Warren et al. 2009; Yelverton 2009). Amicarbazone is a nonionizable, moderately lipophilic (log $K_{OW} = 1.23$ at pH 7) compound that readily dissolves in water (water solubility = 4,600 mg L^{-1} at pH 7), and has a low affinity for soil sorption as denoted by its soil–water organic carbon partition coefficient ($K_{OC} = 23$ to 37; silt loam medium), suggesting plant uptake can occur via foliar and root pathways and the herbicide is both xylem and phloem mobile once within the plant (Cobb 1992; Kirkwood 1991; Senseman 2007).

Previous research has shown selective POST herbicide placement can enhance weed control in turfgrass systems (Brosnan and Breeden 2012; Lycan and Hart 2006a; Williams et al. 2004). To date, reports on this topic with amicarbazone suggest absorption occurs via foliar and root tissue; however, the latter pathway is more detrimental to plant growth (Dayan et al. 2009; Negrisoli et al. 2007; Perry et al. 2011). Dayan et al. (2009) found corn (*Zea mays* L.), large crabgrass [*Digitaria sanguinalis* (L.) Scop.], and velvetleaf (*Abutilon theophrasti* Medik.) photosynthetic electron transport rates (PETRs) were all reduced over time from foliage-only and soil-only amicarbazone placements; however, large crabgrass and velvetleaf PETR reductions were consistently greater than corn, confirming that this compound could provide selective weed control in corn systems (Dewar 2003). Although a foliar application was not included for comparison, Negrisoli et al. (2007) reported weed control was highest when amicarbazone was applied directly to the soil or immediately leached from herbicide-treated sugarcane (*Saccharum officinarum* L.) straw with 30 mm rainfall (the maximum water volume evaluated), indicating herbicide sorption occurred via root uptake. Greenhouse experiments conducted on annual bluegrass amicarbazone uptake followed similar trends; weed control and quantum yield reduction 21 DAT were 100% for soil placements (soil-only and foliage-plus-soil), whereas foliage-only placement had significantly less impact on plant growth (Perry et al. 2011). Although the effect of amicarbazone placement on annual bluegrass growth has been reported, responses on creeping bentgrass growth have not been documented. Considering that these species have different growth patterns and pesticide tolerances (Lush 1988; Vargas and Turgeon 2004), data comparing effects of amicarbazone placement on annual bluegrass and creeping bentgrass could clarify amicarbazone utility in creeping bentgrass systems. The objective of this research was to determine the effect of POST amicarbazone placement on annual bluegrass and creeping bentgrass growth.

Materials and Methods

Growth chamber experiments were conducted in 2010 and 2011 at the Southeastern Plant Environment Laboratory, North Carolina State University, Raleigh, NC to investigate the effect of soil-only, foliage-only, and foliage-plus-soil placements of amicarbazone (Xonerate 70 WG®; Arysta LifeScience Corp., Cary, NC) and bispyribac-sodium (Velocity 17.6 SG®; Valent U.S.A. Corp., Walnut Creek, CA) on annual bluegrass and 'Penn A1' creeping bentgrass growth. Chambers provided 24/13 (± 1) C day/night temperatures with a 14-h day length period. The measured photosynthetically active radiation flux at plant level was 555 μmol m^{-2} s^{-1}. Locally collected annual bluegrass seed (Thorndale Country Club, Oxford, NC) and 'Penn A1' creeping bentgrass seed (Tee-2-Green Corp., Hubbard, OR) were sown into plastic pots (182 cm^2 surface area, 1,670 cm^3 volume) filled with a sand-based growth medium (pH 6.2) containing 2.6% organic matter. A surplus of pots was established to allow selection of uniform plants at experiment initiation. Plants were irrigated by hand twice daily, fertilized weekly with a complete fertilizer (Peters Professional 20–20–20 Water Soluble Fertilizer; Scotts-Sierra Horticultural Products Co., Marysville, OH) at 1.2 g N m^{-2}, and clipped weekly to a 3.75-cm height. Fertilizer applications were not made 2 wk before or after herbicide treatment. Herbicide treatments were applied following a 90-d maturation period, when annual bluegrass plants averaged 10 to 14 tillers and creeping bentgrass plants covered 33 cm^2 of the soil surface as determined by digital image analysis (DIA).

Experiments were conducted as a randomized complete block design with four replicates of a 2 by 3 by 3 factorial treatment arrangement. Factors included two grass species (annual bluegrass or creeping bentgrass), three herbicides (amicarbazone at 49 or 147 g ha^{-1}, or bispyribac-sodium at 74 g ha^{-1}), and three herbicide placements (foliage-only, soil-only, or foliage-plus-soil). A nontreated check was included in each replicate for comparison. Pots were rerandomized weekly to minimize chamber microclimate effects. All herbicides included a nonionic surfactant (Induce®; Helena Chemical Co., Collierville, TN) at 0.25% v/v. Foliage-only and foliage-plus-soil placements were applied with a hand-held CO_2-pressurized sprayer calibrated to deliver 304 L ha^{-1} with one 8002E flat fan nozzle (TeeJet® flat-fan nozzles; Spraying Systems Co., Wheaton IL) at 262 kPa. Herbicide–soil contact was inhibited from foliage-only placements by spreading activated charcoal (BL Powdered Activated Carbon®; Calgon Carbon Corp., Pittsburgh, PA) over the soil surface to a 2.5 cm depth prior to treatment. The activated charcoal barrier was removed 24 h after treatment. Soil-only treatments were prepared by diluting the appropriate amount of active ingredient that would contact the soil surface for a given herbicide application rate in 10 ml of tap water. Herbicide solutions were then uniformly syringed over the soil surface; contact with foliage was prevented. Pots were not irrigated 24 h prior to and 48 h following herbicide treatment. High amicarbazone water solubility (4,600 mg L^{-1} from pH 4 to 9) required that measures be taken to irrigate pots without moving herbicide to nontarget areas (Senseman 2007). Water was syringed every other day over the soil surface to replenish soil moisture content to 90% capacity for 14 DAT. Soil moisture capacities were determined for each pot before trials were initiated by subtracting the average weight of eight unused pots not irrigated for a 14 d period from the weight of a given pot 3 h following saturation. Pots were weighed every other day and the difference between 90% soil capacity and the measured pot weight was converted to a water volume. After this time period, aforementioned irrigation methods resumed. Finally, grass foliage was not clipped for 28 d

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Table 1. Analysis of variance for annual bluegrass and creeping bentgrass clipping mass reduction, aboveground biomass reduction, root mass reduction, and green foliage coverage reduction following treatment with amicarbazone and bispyribac-sodium.[a–d]

		28 DAT		56 DAT		
Source of variation	df	Clipping mass	Green foliage coverage	Root mass	Aboveground biomass	Green foliage coverage
		% reduction				
Run (R)	1	NS	NS	NS	NS	NS
Species (S)	1	NS	***[e]	***	***	***
Herbicide (H)	2	NS	***	***	***	***
Placement (P)	2	***	***	***	***	***
R by S	1	NS	**	NS	NS	NS
R by H	2	NS	NS	NS	NS	NS
R by P	2	NS	NS	NS	NS	NS
S by H	2	NS	***	NS	*	***
S by P	2	*	***	*	NS	***
H by P	4	NS	***	*	***	***
R by S by H	2	NS	NS	NS	NS	NS
R by S by P	2	NS	NS	NS	NS	NS
R by H by P	4	NS	NS	NS	NS	NS
S by H by P	4	NS	***	NS	NS	***
R by S by H by P	4	NS	NS	NS	NS	NS

[a] Abbreviations: DAT, days after treatment; R, experimental run; S, species; H, herbicide; P, placement; NS, not significant at $P = 0.05$ level.

[b] Percent mass reduction and coverage reduction data are relative to the nontreated check within a given replicate.

[c] All mass reduction data are based on dried samples.

[d] Green foliage coverage measured using SigmaScan software on a 0 to 100% scale, based on 0 = no green foliage and 100 = complete green foliage coverage.

*, **, and ***; Significant at $P < 0.05$, $P < 0.01$, and $P < 0.001$, respectively.

following herbicide treatment. The experiment was repeated in time with one run in each of 2 yr.

Digital image analysis was performed 14, 28, 42, and 56 DAT to determine percent green foliage coverage within an experimental unit using SigmaScan Pro (SigmaScan Pro®, Version 5; Systat Software, Inc., Chicago, IL) as previously described (Karcher and Richardson 2005; Richardson et al. 2001). Images were captured utilizing a digital camera (Canon PowerShot SD750®; Canon, Inc., Lake Success, NY) mounted to a tripod (Sony VCT-R649 Lightweight Tripod®; Sony Corporation of America, New York, NY) with the tripod neck fully extended 90° from vertical, 51 cm directly above each pot. Green foliage coverage was quantified and used to calculate percent green foliage cover reduction relative to the nontreated check using the equation:

$$\%\text{cover} = [((C_{NT} - C_T)/C_{NT}) \times 100] \qquad [1]$$

where C_T and C_{NT} represented coverage in treated and nontreated pots, respectively. Plants were clipped to a 2.5 cm height 28 DAT and oven-dried (14 d at 70 C) clipping mass was recorded. All plants were allowed to regrow before destructive sampling 56 DAT. At that time, aboveground biomass was harvested at the soil surface and roots were washed free of soil. Samples were dried under the same conditions as previously described for clippings. After the 14 d drying period, aboveground biomass was recorded and root mass was determined through loss on ignition testing (Koshi 1997). Samples were ashed in a muffle furnace at 500 C for 12 h, and root mass was determined by subtracting the initial sample mass from the residual mineral mass. Reductions in clipping mass, aboveground biomass, and root mass were calculated identically to reductions in percent green foliage cover.

Data were subjected to ANOVA ($P = 0.05$). Plant species, herbicide, herbicide placement, and experimental run were considered fixed effects (Table 1). Main effects and their interactions are presented accordingly, with precedent given to interactions of increasing magnitude (Steele et al. 1997). Means were separated according to Fisher's protected LSD ($P < 0.05$) with the use of SAS general linear models (Statistical Analysis Software®; Version 9.2, SAS Institute, Inc., Cary, NC).

Results and Discussion

Clipping Mass Reduction. A species-by-herbicide placement interaction was detected in clipping mass reduction data 28 DAT (Table 1). Pooled over herbicide, soil-only and foliage-plus-soil placements caused greater annual bluegrass clipping mass reductions (47 and 64%, respectively) than foliage-only placement (16%) (Table 2). No differences were observed among placement levels within creeping bentgrass; however, all placement levels caused 31 to 45% clipping mass reductions. These reductions in vegetative growth are concerning for turfgrass managers because of the reduced recuperative ability of creeping bentgrass. Further, actively growing turfgrass is necessary for optimal root production in the spring season when amicarbazone and bispyribac-sodium applications are recommended (Anonymous 2010; Anonymous 2012). Impacts from reduced vegetative growth in the spring season could result in decreased heat and drought stress tolerance during stressful summer conditions (Carrow 1996).

Aboveground Biomass Reduction. Significant plant species-by-herbicide and herbicide-by-herbicide placement interactions were detected in aboveground biomass reduction data 56 DAT (Table 1). Pooled over herbicide placement, amicarba-

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Table 2. Species-by-herbicide placement interaction in clipping mass reduction data 28 DAT with amicarbazone and bispyribac-sodium.[a–c]

Placement	POAAN	AGSST
	%	
Foliage-only	16	31
Soil-only	47	31
Foliage-plus-soil	64	45
$LSD_{0.05}$	16	NS

[a] Abbreviations: DAT, days after treatment; POAAN, annual bluegrass; AGSST, creeping bentgrass; NS, not significant at P = 0.05.

[b] Percent oven-dried clipping mass reduction, relative to the nontreated check.

[c] Data pooled over herbicides.

zone at 49 and 147 g ha^{-1} responded similarly, causing 64 and 71% reductions in annual bluegrass biomass, respectively, whereas bispyribac-sodium only caused a 31% reduction (Table 3). Creeping bentgrass biomass reductions followed similar trends, with amicarbazone at 49 and 147 g ha^{-1} causing 29 and 42% reductions, respectively, whereas bispyribac-sodium only caused a 15% reduction. No differences were detected between amicarbazone application rates. Although direct comparisons between species cannot be made, responses with bispyribac-sodium support previous research that the compound can selectively reduce annual bluegrass growth in creeping bentgrass systems (Lycan and Hart 2006b; Teuton et al. 2007). Pooled over plant species, aboveground biomass reduction 56 DAT was dependent on soil exposure for both amicarbazone application rates; no differences were detected between placements including soil contact (soil-only and foliage-plus-soil). Foliage-only placement of amicarbazone at 49 and 147 g ha^{-1} reduced biomass 25 and 27%, respectively, whereas soil-only and foliage-plus-soil placements caused 56 to 72% reductions. Bispyribac-sodium responded similarly regardless of placement. Contrary to these data, Lycan and Hart (2006a) reported soil-only and foliage-plus-soil placements of bispyribac-sodium applied at 148 or 296 g ha^{-1} caused more annual bluegrass and creeping bentgrass shoot growth reduction than foliar-only applications 28 DAT. Discrepancies between results might be explained by our use of a lower herbicide application rate, more mature plants, a greater rooting volume, and later aboveground biomass assessments following trial initiation.

Root Mass Reduction. Plant species-by-herbicide placement and herbicide-by-herbicide placement interactions were detected in root mass reduction data 56 DAT (Table 1). Pooled over herbicide, no differences were detected between placements including soil contact for either species evaluated (Table 4). In general, foliage-only herbicide placement resulted in less annual bluegrass and creeping bentgrass root mass reduction (13 to 35%) than soil placements (40 to 67%). Pooled over plant species, no differences were detected between placements including soil contact for both amicarbazone application rates. Averaged over placements including soil contact, root mass reductions from amicarbazone at 49 and 147 g ha^{-1} more than doubled foliage-only placement. Bispyribac-sodium responded similarly regardless of placement, reducing root mass 19 to 27%.

Green Foliage Cover Reduction. A plant species-by-herbicide-by-herbicide placement interaction was detected in green foliage coverage reduction data 28 and 56 DAT (Table 1). For each data collection date, the effect of plant species and herbicide placement (within each herbicide) is presented first, followed by the effect of herbicide and herbicide placement (within each species).

Annual bluegrass and creeping bentgrass responded similarly to foliage-only placement of amicarbazone at 49 g ha^{-1} 28 DAT; this treatment reduced green foliage cover 6 to 12% (Table 5). Plant species responded differently to soil-only and foliage-plus-soil placements of amicarbazone at 49 g ha^{-1}. Soil-only amicarbazone placement on annual bluegrass and creeping bentgrass caused 49 and 7% green foliage coverage reductions, respectively, whereas foliage-plus-soil placement caused 58 and 7% reductions, respectively. Differences in green foliage cover reductions were detected between annual bluegrass and creeping bentgrass with all placements of amicarbazone at 147 g ha^{-1}. Foliage-only, soil-only, and foliage-plus-soil placements caused 16, 63, and 68% annual bluegrass green foliage cover reductions, respectively. Comparatively, these treatments only resulted in 4 to 8% reductions in creeping bentgrass green foliage coverage 28 DAT. Annual bluegrass and creeping bentgrass responded differently to foliage-only and foliage-plus-soil placements of bispyribac-sodium as well. Annual bluegrass green foliage coverage was reduced 30 to 37% from foliage-only and foliage-plus-soil placements compared to 6 to 7% for creeping bentgrass.

In general, annual bluegrass green foliage coverage was reduced more by placements including soil contact, than

Table 3. Species-by-herbicide and herbicide-by-herbicide placement interactions in aboveground biomass reduction data 56 DAT with amicarbazone and bispyribac-sodium.[a,b]

Herbicide[c]	g ha^{-1}	POAAN	AGSST	Foliage-only	Soil-only	Foliage-plus-soil	LSD[d]
		%			%		
Amicarbazone	49	64	29	25	56	62	14
Amicarbazone	147	71	42	27	72	72	10
Bispyribac-sodium	74	31	15	27	16	28	NS
LSD[e]		9	14				

[a] Abbreviations: DAT, days after treatment; POAAN, annual bluegrass; AGSST, creeping bentgrass; NS, not significant at P = 0.05.

[b] Percent oven-dried aboveground biomass reduction, relative to the nontreated check.

[c] All herbicides applied with a nonionic surfactant at 0.25% v/v.

[d] LSD ($P < 0.05$) for comparing herbicide placement and herbicide, pooled over species.

[e] LSD ($P < 0.05$) for comparing species and herbicide, pooled over herbicide placement.

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Table 4. Species-by-herbicide placement and herbicide-by-herbicide placement interactions in root mass reduction data 56 DAT with amicarbazone (at two different concentrations) and bispyribac-sodium.[a–d]

Placement	POAAN	AGSST	Amicarbazone, 49 g ha^{-1}	Amicarbazone, 147 g ha^{-1}	Bispyribac-sodium, 74 g ha^{-1}
	%		%		
Foliage-only	35	13	30	23	19
Soil-only	62	40	63	72	18
Foliage-plus-soil	67	40	60	73	27
$LSD_{0.05}$	10	8	12	7	NS

[a] Abbreviations: DAT, days after treatment; POAAN, annual bluegrass; AGSST, creeping bentgrass; NS, not significant at P = 0.05.

[b] Root mass determined by loss on ignition testing.

[c] Percent root mass reduction, relative to the nontreated check.

[d] All herbicides applied with a nonionic surfactant at 0.25% v/v.

foliage-only placement. Soil-only and foliage-plus-soil placements of amicarbazone reduced green foliage coverage 49 to 68%, whereas foliage-only placement caused 12 to 16% coverage reductions 28 DAT (Table 5). No differences were observed between placements including soil contact at either amicarbazone application rate. Within creeping bentgrass, no differences were detected between herbicide and herbicide placement on green foliage coverage reduction 28 DAT. Creeping bentgrass coverage was reduced ≤ 8% with all treatments.

Annual bluegrass and creeping bentgrass responded differently to all placements of amicarbazone at 49 or 147 g ha^{-1} 56 DAT. Foliage-only, soil-only, and foliage-plus-soil placements of amicarbazone at 49 g ha^{-1} caused 32, 74, and 76% annual bluegrass green foliage cover reductions, respectively, whereas creeping bentgrass coverage was only reduced –0.8, 2.3, and 6.5%, respectively (Table 6). Negative coverage reduction values denote an increase in coverage relative to the nontreated check. Foliage-only, soil-only, and foliage-plus-soil placements of amicarbazone at 147 g ha^{-1} caused 18, 83, and 83% reductions in annual bluegrass green foliage coverage, respectively, compared to −1.5, 0.5, and 2.3%, respectively, for creeping bentgrass. Varying responses between species also occurred with foliage-only and foliage-plus-soil placements of bispyribac-sodium. Annual bluegrass green foliage coverage was reduced 34 and 27% from foliage-only and foliage-plus-soil placements of bispyribac-sodium, respectively, whereas creeping bentgrass green foliage coverage was increased 1.6 and 0.9%, respectively, relative to the nontreated check.

Herbicide placement had a significant impact on annual bluegrass green foliage coverage reduction with both rates of amicarbazone 56 DAT. In general, annual bluegrass green foliage coverage was reduced more by placements including soil contact than foliage-only placement (Table 6). Soil-only and foliage-plus-soil placements of amicarbazone caused 74 to 83% coverage reductions compared to 18 to 32% reductions following foliage-only placement. Although slight differences in green foliage cover reductions were observed between herbicide placements 56 DAT, no treatment reduced creeping bentgrass green foliage coverage > 7%. These data are

Table 5. Effect of herbicide and herbicide placement on annual bluegrass and creeping bentgrass green foliage coverage reductions 28 DAT with amicarbazone and bispyribac-sodium.[a–c]

Herbicide[d]	g ha^{-1}	Placement	POAAN	AGSST	LSD[e]
			%		
Amicarbazone	49	Foliage-only	12	6	15
	49	Soil-only	49	7	
	49	Foliage-plus-soil	58	7	
Amicarbazone	147	Foliage-only	16	4	10
	147	Soil-only	63	8	
	147	Foliage-plus-soil	68	7	
Bispyribac-sodium	74	Foliage-only	30	7	20
	74	Soil-only	12	8	
	74	Foliage-plus-soil	37	6	
LSD[f]			19	NS	

[a] Abbreviations: DAT, days after treatment; POAAN, annual bluegrass; AGSST, creeping bentgrass; NS, not significant at P = 0.05.

[b] Percent green foliage coverage reduction, relative to the nontreated check.

[c] Green foliage coverage measured using SigmaScan software on a 0 to 100% scale, based on 0 = no green foliage and 100 = complete green foliage coverage.

[d] All herbicides applied with a nonionic surfactant at 0.25% v/v.

[e] LSD ($P < 0.05$) for comparing herbicide placement and species within a herbicide.

[f] LSD ($P < 0.05$) for comparing herbicide and herbicide placement within a species.

Table 6. Effect of herbicide and herbicide placement on annual bluegrass and creeping bentgrass green foliage coverage reductions 56 DAT with amicarbazone and bispyribac-sodium.[a–d]

Herbicide[e]	g ha^{-1}	Placement	POAAN	AGSST	LSD[f]
			%		
Amicarbazone	49	Foliage-only	32	−0.8	11
	49	Soil-only	74	2.3	
	49	Foliage-plus-soil	76	6.5	
Amicarbazone	147	Foliage-only	18	−1.5	10
	147	Soil-only	83	0.5	
	147	Foliage-plus-soil	83	2.3	
Bispyribac-sodium	74	Foliage-only	34	−1.6	20
	74	Soil-only	12	0.1	
	74	Foliage-plus-soil	27	−0.9	
LSD[g]			20	3.6	

[a] Abbreviations: DAT, days after treatment; POAAN, annual bluegrass; AGSST, creeping bentgrass.

[b] Percent green foliage coverage reduction, relative to the nontreated check.

[c] Green foliage coverage measured using SigmaScan software on a 0 to 100% scale, based on 0 = no green foliage and 100 = complete green foliage coverage.

[d] Negative green foliage coverage reduction values indicate an increase in green foliage coverage, relative to the nontreated check.

[e] All herbicides applied with a nonionic surfactant at 0.25% v/v.

[f] LSD ($P < 0.05$) for comparing herbicide placement and species within a herbicide.

[g] LSD ($P < 0.05$) for comparing herbicide and herbicide placement within a species.

somewhat misleading, because creeping bentgrass aboveground biomass was reduced > 28% (Table 3) at this evaluation date. This is best explained by the production of elongated grass blades with increased moisture content following amicarbazone applications to creeping bentgrass (personal observation; data not shown), a response not detected using DIA methodology.

Based on our results, amicarbazone effects on annual bluegrass and creeping bentgrass are influenced by herbicide placement. Although plant sorption can occur via foliar and root pathways, amicarbazone was more detrimental to plant growth in our research when applied to the soil surface. Perry et al. (2011) reported similar results; soil-only and foliage-plus-soil amicarbazone placements provided 100% annual bluegrass control 21 DAT, whereas foliage-only placement had significantly less impact on plant growth. Across herbicide placements, annual bluegrass was more affected than creeping bentgrass by amicarbazone, supporting use of this compound for selective annual bluegrass control in creeping bentgrass. Across species and amicarbazone application rates, placements including soil contact reduced plant growth more than foliage-only placements. These data can be explained in part by findings from Yu et al. (2013); these authors detected 40% more root-applied ^{14}C amicarbazone in annual bluegrass shoots than in creeping bentgrass. Further, creeping bentgrass metabolized amicarbazone more rapidly than annual bluegrass 1 to 7 DAT. Finally, differences between soil-only and foliage-plus-soil placements were not detected in the current study, suggesting that amicarbazone uptake via roots is more detrimental to plant growth than uptake via foliage. Soil placements of amicarbazone reduced annual bluegrass growth more than bispyribac-sodium, confirming that this compound might provide an alternative POST annual bluegrass chemical control option for end-users; however, turfgrass injury from amicarbazone soil placement is a point of concern. Unacceptable injury is most likely due to plant maturity at application and climatic conditions following an application (Brosnan et al. 2013; McCullough et al. 2010). Brosnan et al. (2013) reported creeping bentgrass injury 28 DAT increased 25% as rooting depth at application decreased from 15 cm to 5 cm, whereas McCullough et al. (2010) reported that creeping bentgrass injury following amicarbazone applied at 200 g ha^{-1} increased approximately 90% as chamber temperatures increased from 10 to 30 C. For this reason, turfgrass managers should ensure creeping bentgrass systems are well established and climatic conditions promote healthy plant growth before implementing application methods favoring amicarbazone–soil contact. Future research should address methods to promote herbicide–soil contact including cultural practices to increase soil exposure and postapplication irrigation management.

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