Preemergence Herbicide Efficacy for Crabgrass (*Digitaria* spp.) Control in Common Bermudagrass Managed under Different Mowing Heights

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Abstract. Research was conducted at multiple locations throughout the southeastern United States during 2012 and 2013 to assist turf managers in developing integrated programs for managing crabgrass in common bermudagrass turf. Our objective was to determine the effect of mowing height on the efficacy of several pre-emergent (PRE) herbicides labeled for crabgrass control in bermudagrass turf. Plots were established in Raleigh, NC (NCSU), Knoxville, TN (ETREC), and Winder, GA (UGA) and treated with a factorial combination of two mowing heights (1.5 or 3.8 cm), two application regimes [single or split application (initial and an 8-week sequential)], and six preemergent herbicides (dithiopyr, indaziflam, oxadiazon, pendimethalin, prodiamine, and prodiamine + sulfentrazone). In 2012, all herbicides provided greater crabgrass control on plots maintained at 3.8 cm compared with 1.5 cm. This response was not detected in 2013, potentially as a result of above-average rainfall at two of the three trial locations. Analysis revealed mowing height did not affect pendimethalin soil residue, whereas prodiamine concentrations from bermudagrass maintained at 1.5 cm were greater than bermudagrass maintained at 3.8 cm. Therefore, differences in crabgrass control in bermudagrass maintained under different mowing heights may be the result of plant growth, reduced photosynthetically active radiation (PAR) at the soil surface, among other reasons, and not solely differential degradation of applied herbicides at the 1.5- and 3.8-cm mowing heights. Future research should explore effects of increasing bermudagrass mowing height on PAR required for crabgrass germination and growth.

Crabgrass (*Digitaria* spp.) is a common weed of warm- and cool-season turfgrasses. A survey of the southern United States conducted by Webster (2000) ranked crabgrass as the most common turfgrass weed in 10 of 12 southern states. Compared with desirable turfgrass species such as bermudagrass (*Cynodon* spp.) or tall fescue (*Lolium arundinaceum* Schreb.), the light green color and coarse texture of crabgrass foliage can reduce overall turf quality (Hall et al., 1994). PRE herbicides such as dithiopyr, indaziflam, oxadiazon, prodiamine, and pendimethalin are labeled for selective control of smooth crabgrass (*Digitaria ischaemum* Schreb.) and large crabgrass [*Digitaria sanguinalis* (L.) Scop.]

in turf (Anonymous, 2012a, 2012b, 2012c, 2007, 2009).

Previous research has reported reductions in crabgrass cover by increasing turf mowing height. Specifically, Dernoeden et al. (1993) reported ≈3% smooth crabgrass cover in non-treated tall fescue mowed at 8.8 cm compared with 40% and 80% smooth crabgrass cover in plots mowed at 5.5 and 3.2 cm, respectively, at the conclusion of a 3-year study. Reductions in smooth crabgrass cover with increased mowing height have been observed in other cool-season turfgrass species, including kentucky bluegrass (*Poa pratensis* L.), tall fescue, perennial ryegrass (*Lolium perenne* L.), and several fine fescue species (*Festuca* spp.) (Debels et al., 2012; Dernoeden et al., 1998; Dunn et al., 1981; Jagschitz and Ebdon, 1985; Voigt et al., 2001). To date, minimal information has been published regarding effects of mowing height on crabgrass cover in warm-season

turfgrass species such as common bermudagrass (*Cynodon dactylon* L.) (Callahan, 1978; Hoyle et al., 2014).

Integrated pest management has been defined as the thoughtful combination of multiple approaches such as synthetic chemical applications and cultural practices to control pests (Busey, 2003). Although the efficacy of PRE herbicides for crabgrass control and effects of mowing height on crabgrass incidence have been studied, research exploring the integration of these two practices is limited. Dernoeden et al. (1993) monitored smooth crabgrass cover after applications of dithiopyr and pendimethalin to tall fescue turf maintained at 8.8, 5.5, and 3.2 cm. Herbicide rates were reduced by 50% at the end of the 3-year study and plots mowed at 5.5 and 8.8 cm did not require a herbicide in the final year of the experiment. Smooth crabgrass cover in dithiopyr- or pendimethalin-treated plots was similar (3% or less) during the first 2 years of the study, regardless of mowing height. However, in the third year, smooth crabgrass cover was greater in tall fescue turf mowed at 3.2 and 5.5 cm than 8.8 cm after pendimethalin or dithiopyr application. The researchers concluded that annual dithiopyr or pendimethalin applications at labeled rates would be required when mowing tall fescue at 3.2 and 5.5 cm. However, reduced rates and less frequent applications of these herbicides could provide acceptable turf quality when mowing height was increased to 8.8 cm.

Changes in common bermudagrass mowing height may affect the efficacy of PRE herbicides labeled for crabgrass control. However, minimal data have been published regarding integrated programs for managing crabgrass infestations using PRE herbicides in combination with mowing height adjustment. Therefore, the objective of this research was to determine the effect of mowing height on the efficacy of several PRE herbicides labeled for crabgrass control in common bermudagrass turf.

Materials and Methods

Field study. Field research to evaluate select PRE herbicides labeled for crabgrass control in common bermudagrass turf managed under different mowing heights was conducted at the East Tennessee Research and Education Center–Plant Sciences Unit (ETREC) in Knoxville, TN (lat. 35.54° N, long. 83.57° W) during 2012 and 2013. This experiment was repeated in 2013 at North Carolina State University Turf Field Laboratory (NCSU) in Raleigh, NC (lat. 35.73° N, long. 78.67° W) and Pine Hills Golf Club (UGA) in Winder, GA (lat. 33.97° N, long. 83.69° W) to evaluate treatment response across a wider geographic region of the southeastern United States.

At all locations, research was conducted on established common bermudagrass. At NCSU and ETREC, plots (1 × 2.5 m and 1.5 × 2.4 m, respectively) were established in areas with a history of smooth crabgrass incidence, whereas large crabgrass was the predominant species at

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UGA (1.5 × 3-m plots). Soil type at NCSU was a Cecil sandy clay loam (fine, kaolinitic, thermic typic Kanhapludult), measuring 6.4 in soil pH and 1.9% in organic matter. Soil type at ETREC was a Sequatchie loam soil (fine-loamy, siliceous, semiactive, thermic humic Hapludult), measuring 6.2 in soil pH and 2.1% in organic matter. At the UGA location, soil was a Madison sandy clay loam (fine, kaolinitic, thermic typic Kanhapludult) with a pH of 5.1 and 0.7% organic matter. In both years, turf at ETREC received two fertilizer applications at 49 kg nitrogen (N)/ha in spring (March, April) from a complete fertilizer (21.0N–0.4P₂O₅–13.3K₂O; Harrell's LLC, Charlotte, NC). Supplemental nutrition was applied similarly at NCSU with two applications (April, June) made at 49 kg N/ha from a complete fertilizer (25.0N–2.6P₂O₅–10.0K₂O; Harrell's LLC). Fertilizer (16.0N–1.7P₂O₅–6.6K₂O; Griggs Brothers, Albion, ID) was applied at UGA at a rate of 49 kg N/ha in April and June. To prevent wilt, overhead irrigation was applied to supplement rainfall at each location. Additionally, plots at all locations received ≈0.5 cm of irrigation within 24 h of herbicide or fertilizer applications.

Treatments included a factorial combination of two mowing heights (1.5 or 3.8 cm), two application regimes (single or split applications with split treatments applied at initial application and 8 weeks later), and six PRE herbicides including: dithiopyr (Dimension; Dow AgroSciences, Indianapolis,

IN), indaziflam (Specticle; Bayer Environmental Sciences, Research Triangle Park, NC), oxadiazon (Ronstar; Bayer Environmental Sciences), pendimethalin (Pendulum AquaCap; BASF Corporation, Research Triangle Park, NC), prodiamine (Barricade; Syngenta Professional Products, Greensboro, NC), and prodiamine + sulfentrazone (Echelon; FMC Corporation, Philadelphia, PA). Herbicide application rates and dates are presented in Tables 1 and 2. All herbicides except oxadiazon used water as the carrier and were applied with CO₂-powered backpack sprayers at all locations. Carrier volumes at ETREC, NCSU, and UGA were 280, 304, and 280 L·ha⁻¹, respectively, using flat-fan nozzles (XR8002; TeeJet Technologies, Wheaton, IL). A granular formulation of oxadiazon was applied at all locations with a shaker jar.

Plots were mowed at 1.5 or 3.8 cm at all locations beginning 4 weeks before herbicide treatment. Plots maintained at 1.5 cm were mowed three times per week, whereas those maintained at 3.8 cm were mowed two times per week. In all cases, clippings were returned. ETREC maintained 1.5-cm and 3.8-cm plots with reel (Jacobsen LF 3800; Jacobsen, A Textron Company, Charlotte, NC) and rotary (Gravely Zero Turn; An Ariens Company, Brillion, WI) mowers, respectively. Rotary mowers were used to maintain both 1.5-cm (Honda HRC 215; American Honda Motor Company, Duluth, GA) and 3.8-cm (John Deere 997 Zero-Turn;

Deere and Company, Moline, IL) plots at NCSU. Plots at UGA were maintained at 1.5 cm with a reel mower (Toro Reelmaster 5500-D; The Toro Company, Bloomington, MN) and 3.8 cm with a rotary mower (Toro Groundsmaster 3320; The Toro Company). Nontreated plots were also included for each mowing height.

Crabgrass control was visually evaluated on a 0% (no control) to 100% (complete control) scale 12, 16, 20, and 24 weeks after initial treatment (WAIT) in 2012 and 2013. Crabgrass plant counts were also taken 24 WAIT in 2013 using a 1-m² grid (10 cm × 10 cm spacing) placed in the center of each plot. All count data are expressed as a percent reduction compared with the non-treated control at each respective mowing height.

The experimental design was a randomized complete block with three replications at ETREC and UGA and four replications at NCSU. Crabgrass control data were arcsine-transformed before being subjected to analysis of variance in SAS (SAS Version 9.1; SAS Institute, Cary, NC) using expected means squares described by McIntosh (1983) for multiple location experiments. Interpretations of arcsine- and non-transformed data were similar; therefore, non-transformed means are presented for clarity. Data from the 2012 and 2013 experiments were analyzed separately. Significant treatment-by-location interactions were detected in 2013 data collected at ETREC, NCSU, and UGA; therefore, data from all 2013 experiments were analyzed and presented separately. In both years, Fisher's protected least significant difference (LSD) test was used to separate treatment means at the $\alpha = 0.05$ level. Pearson's correlation coefficients were also calculated to evaluate relationships between visual assessments of crabgrass control and plant counts.

Residue analysis. Laboratory experiments were conducted in 2013 to determine the effect of mowing height on prodiamine and pendimethalin residue from field research plots at ETREC and NCSU. Prodiamine and pendimethalin were selected because they are commonly used PRE herbicides in established common bermudagrass areas. Furthermore, each are dinitroaniline herbicides with varying persistence. Prodiamine and pendimethalin have moderate to persistent and short to moderate half-lives, respectively, in soil (Senseman, 2007). Single soil cores (2.5 × 2.5 × 2.0 cm)

Table 1. Preemergent herbicide treatments evaluated in Knoxville, TN, Raleigh, NC, and Winder, GA, during 2012 and 2013.^a

Application regime ^b	Herbicide	Rate (g·ha ⁻¹)
Single	Dithiopyr	560
	Indaziflam	52.5
		35
	Oxadiazon	4,500
	Pendimethalin	3,360
	Prodiamine	1,680
Split	Prodiamine + sulfentrazone	854 + 416
	Dithiopyr	280 fb ^c 280
	Indaziflam	26.25 fb 26.25
		17.5 fb 17.5
	Oxadiazon	2,250 fb 2250
	Pendimethalin	1,680 fb 1680
	Prodiamine	840 fb 840
	Prodiamine + sulfentrazone	427 + 208 fb 427 + 208

^aApplications were made to common bermudagrass turf areas maintained at 1.5 and 3.8 cm.

^bAll herbicides received ≈0.5 cm of irrigation or rainfall within 24 h of application. Split applications were applied initially and 8 weeks later.

^cfb = followed by.

Table 2. Calendar dates and environmental conditions when applying preemergent herbicides during 2012 and 2013 in Knoxville, TN (ETREC), Raleigh, NC (NCSU), and Winder, GA (UGA).

Yr	Location	Application regime	Calendar date	Air temp	Soil temp	Avg high/low air temp during data collection	Rainfall during data collection (cm)
				----- (°C) -----			
2012	ETREC	Single	6 Mar.	20	13	29/14	48.5
2013	ETREC	Split	6 Mar. fb 30 Apr.	20 fb 31	13 fb 26	—	—
		Single	14 Mar.	6	6	26/14	86.5
	NCSU	Split	14 Mar. fb 7 May	6 fb 21	6 fb 21	—	—
		Single	15 Mar.	9	8	25/14	56.5
	UGA	Split	15 Mar. fb 10 May	9 fb 27	8 fb 23	—	—
		Single	8 Mar.	12	11	26/15	94.2
		Split	8 Mar. fb 3 May	12 fb 20	11 fb 18	—	—

ETREC = East Tennessee Research and Education Center—Plant Sciences Unit; NCSU = North Carolina State University Turf Field Laboratory; UGA = Pine Hills Golf Club; fb = followed by.

were collected from the center of each plot using a soil probe (AMS Inc., America Falls, ID) at 0 and 24 WAIT. Initial samples (0 WAIT) were collected by removing the above-ground vegetation in a small sampling area within the plot, thereby treating the soil and allowing the herbicides to air-dry for 2 h before collecting the samples. All samples were wrapped in aluminum foil and stored immediately at -20°C until analysis occurred.

Proflam and pendimethalin were extracted according to U.S. EPA Method Number 445276-01 with slight modifications as noted (U.S. Environmental Protection Agency, 1996). Ten grams of soil were placed in a 175-mL polypropylene conical bottom centrifuge bottle and 25 mL deionized water was added and hand-shaken for 15 s. Seventy-five milliliters of 2% acidic methanol was added and shaken on an orbital

shaker for 1 h at 240 rpm. Samples were then centrifuged for 10 min at 4000 rpm and supernatant was decanted. Samples were filtered through a $0.45\text{-}\mu\text{m}$ syringe filter, vialled, and analyzed by an ultra-performance liquid chromatography–tandem mass spectrometer. Residues were quantified based on peak area measurements using appropriate calibration curves with means separated using Fisher's protected LSD test at the $\alpha = 0.05$ level.

Results and Discussion

Field study. By 24 WAIT in 2012, averaged over application regime, all PRE herbicides excluding proflam and indaziflam ($52.5\text{ g}\cdot\text{ha}^{-1}$) provided greater crabgrass control on plots maintained at 3.8 cm compared with 1.5 cm (Table 3). When applied to bermudagrass maintained at 3.8 cm, proflam

controlled crabgrass 97%, similar to indaziflam ($52.5\text{ g}\cdot\text{ha}^{-1}$), oxadiazon, and proflam + sulfentrazone (Table 3).

Significant ($P < 0.0001$) location-by-treatment interactions were detected in crabgrass control and plant count data collected in 2013; therefore, data from the ETREC, NCSU, and UGA locations are presented separately. By 24 WAIT at ETREC, dithiopyr applications to bermudagrass maintained at 3.8 cm controlled crabgrass greater than dithiopyr applied to turf at 1.5 cm (Table 4). Although this is similar to findings from ETREC in 2012, this response was not observed at NCSU or UGA in 2013. At these locations, averaged over application regime, similar crabgrass control was observed with dithiopyr (62% to 78%) regardless of mowing height 24 WAIT (Table 4). Applications of indaziflam at $52.5\text{ g}\cdot\text{ha}^{-1}$ to 3.8 cm turf at ETREC controlled crabgrass less than those made to turf mowed at 1.5 cm in 2013. This response was also observed with indaziflam ($35\text{ g}\cdot\text{ha}^{-1}$) at NCSU (Table 4). No differences in crabgrass control with indaziflam were detected between the 3.8- and 1.5-cm mowing heights at UGA in 2013; however, overall levels of crabgrass control with indaziflam at this location were low by 24 WAIT (20% to 41%). Similar to 2012, proflam ($1680\text{ g}\cdot\text{ha}^{-1}$) provided excellent crabgrass control 24 WAIT (94% to 100%) regardless of location, mowing height, or application regime in 2013.

Location-by-application regime interactions ($P = 0.02$) were also detected in 2013. At ETREC, single and split applications of indaziflam ($35\text{ g}\cdot\text{ha}^{-1}$) controlled crabgrass similarly; however, the level of crabgrass control with these treatments was unacceptable (46% to 50%) by 24 WAIT (Table 5). Application regime affected crabgrass control with the $35\text{ g}\cdot\text{ha}^{-1}$ rate of indaziflam in

Table 3. Mowing height-by-herbicide interactions in smooth crabgrass (*Digitaria ischaemum*) control data collected 24 weeks after treatment in Knoxville, TN (ETREC) in 2012.

Herbicide	Rate ^z ($\text{g}\cdot\text{ha}^{-1}$)	Mowing ht (cm)	Smooth crabgrass control (%)
Dithiopyr	560	3.8	79
	560	1.5	43
Indaziflam	52.5	3.8	87
	52.5	1.5	72
Indaziflam	35	3.8	77
	35	1.5	45
Oxadiazon	4,500	3.8	86
	4,500	1.5	45
Pendimethalin	3,360	3.8	78
	3,360	1.5	56
Proflam	1,680	3.8	97
	1,680	1.5	83
Proflam + sulfentrazone	854 + 416	3.8	80
	854 + 416	1.5	56
LSD _{0.05}			17

^zData are averaged over single and split applications. Split applications were applied initially and 8 weeks later.
ETREC = East Tennessee Research and Education Center–Plant Sciences Unit; LSD = least significant difference.

Table 4. Mowing height-by-herbicide interactions in crabgrass (*Digitaria* spp.) control and plant count data collected 12 and 24 weeks after treatment (WAT) in Knoxville, TN (ETREC), Raleigh, NC (NCSU), and Winder, GA (UGA) in 2013.

Herbicide	Rate ^z ($\text{g}\cdot\text{ha}^{-1}$)	Mowing height (cm)	ETREC			NCSU			UGA		
			Smooth crabgrass control		Plant count ^y	Smooth crabgrass control		Plant count	Large crabgrass control		Plant count
			12 WAT	24 WAT		12 WAT	24 WAT		12 WAT	24 WAT	
			----- (%) -----		(% red.)	----- (%) -----		(% red.)	----- (%) -----		(% red.)
Dithiopyr	560	3.8	100	93	83	100	76	88	100	62	66
	560	1.5	98	60	52	100	78	87	100	66	68
Indaziflam	52.5	3.8	100	65	51	99	79	88	93	40	37
	52.5	1.5	99	88	81	100	83	91	86	20	15
Indaziflam	35	3.8	100	62	45	98	45	42	93	41	38
	35	1.5	96	66	51	100	71	80	90	23	23
Oxadiazon	4,500	3.8	100	91	90	100	83	91	100	57	53
	4,500	1.5	97	83	75	100	94	97	96	59	60
Pendimethalin	3,360	3.8	100	86	80	99	83	94	100	94	94
	3,360	1.5	99	84	79	100	93	98	100	88	83
Proflam	1,680	3.8	100	94	92	100	97	99	98	94	95
	1,680	1.5	100	100	99	100	100	100	100	97	98
Proflam + sulfentrazone	854 + 416	3.8	100	84	82	100	91	97	98	69	72
	854 + 416	1.5	100	94	94	100	84	93	100	68	68
LSD _{0.05}			2	12	NS	1	11	10	NS	NS	11

^zData are averaged over single and split applications. Split applications were applied initially and 8 weeks later.

^yPlant count data were collected 24 WAIT and expressed as a percent reduction relative to the non-treated control.

ETREC = East Tennessee Research and Education Center–Plant Sciences Unit; NCSU = North Carolina State University Turf Field Laboratory; UGA = Pine Hills Golf Club; LSD = least significant difference; NS = nonsignificant; red. = reduction.

Table 5. Application regime-by-herbicide interactions in crabgrass species (*Digitaria* spp.) control and plant count data collected 12 and 24 weeks after treatment (WAT) in Knoxville, TN (ETREC), Raleigh, NC (NCSU), and Winder, GA (UGA) in 2013.

Application regime	Herbicide	Rate (g ha ⁻¹)	ETREC			NCSU			UGA		
			Smooth crabgrass control		Plant count ²	Smooth crabgrass control		Plant count	Large crabgrass control		Plant count
			12 WAT	24 WAT		12 WAT	24 WAT		12 WAT	24 WAT	
			----- (%) -----		(% red.)	----- (%) -----		(% red.)	----- (%) -----		(% red.)
Single	Dithiopyr	560	98	68	53	100	78	89	100	63	68
	Indaziflam	52.5	99	77	59	100	78	88	96	27	23
		35	99	60	46	98	47	52	100	53	52
	Oxadiazon	4,500	99	88	87	100	93	96	100	83	83
	Pendimethalin	3,360	100	78	74	99	88	96	100	87	83
	Prodiamine	1,680	100	98	95	100	98	99	98	93	95
Split	Prodiamine + sulfentrazone	854 + 416	100	83	81	100	89	95	98	55	58
	Dithiopyr	280 fb ³ 280	100	85	82	100	75	86	100	65	66
	Indaziflam	26.25 fb 26.25	99	75	73	99	84	90	83	32	29
		17.5 fb 17.5	98	68	50	99	69	71	83	11	9
	Oxadiazon	2250 fb 2250	98	86	78	100	85	92	96	33	30
	Pendimethalin	1680 fb 1680	99	93	85	100	88	96	100	95	95
	Prodiamine	840 fb 840	100	97	96	100	99	99	100	98	99
	Prodiamine + sulfentrazone	427 + 208 fb 427 + 208	100	96	95	100	87	95	100	82	83
			NS	NS	NS	NS	11	10	5	13	11

²Plant count data were collected 24 WAT and expressed as a percent reduction relative to the non-treated control.³fb = followed by.

ETREC = East Tennessee Research and Education Center–Plant Sciences Unit; NCSU = North Carolina State University Turf Field Laboratory; UGA = Pine Hills Golf Club; LSD = least significant difference; NS = non-significant; red. = reduction.

2013 at NCSU. By 24 WAIT, split applications at 17.5 g·ha⁻¹ controlled crabgrass greater than a single application at 35 g·ha⁻¹. Previous research indicates sequential applications of mitosis-inhibiting PRE herbicides consistently provided season-long crabgrass control (Johnson, 1977; Proctor et al., 2012). The opposite relationship was observed between single and split application regimes of indaziflam at 52.5 and 35 g·ha⁻¹ at 12 WAIT and 35 g·ha⁻¹ by 24 WAIT at UGA. These responses suggest that 35 g·ha⁻¹ of indaziflam may not be a sufficient rate for crabgrass control in bermudagrass turf in the southeastern United States for season-long control. Overall crabgrass control with single and split applications of indaziflam at 35 g·ha⁻¹ in this 2-year study only ranged from 21% to 77%, regardless of mowing height (Tables 3 and 4). With the exception of oxadiazon at UGA, significant differences were not detected between other PRE herbicides applied as a single or as split applications. Relationships among treatments using plant count data were similar to those detected by visual assessments of crabgrass control at each location. Plant count data were significantly correlated ($r = 0.89$, $P < 0.0001$) to visual assessments of crabgrass control 24 WAIT.

Although mowing height had a pronounced effect on crabgrass control with several PRE herbicides in 2012, responses observed in 2013 were indistinct in comparison. This could be the result of variable environmental conditions over years (Table 2). During the data collection period in 2012 at ETREC, daily maximum air temperatures were 3 °C higher (29 °C) and rainfall accumulation (48.5 cm) was considerably lower than 30-year averages for this location (National Climatic Data Center, 2013). The opposite was observed in 2013 because rainfall accumulation during the data collection period (86.5 cm) exceeded the 30-year average by 28% (National Climatic Data Center, 2013). At the UGA site, rainfall accumulation during the data collection period (94.2 cm) in 2013 exceeded the 30-year average by 54% as well (National Climatic Data Center, 2013). Increased rainfall in 2013 may have facilitated greater crabgrass germination compared with 2012, therefore making reductions as a result of increased mowing height less apparent. Several researchers have found crabgrass germination to be maximal when water potential of soil is low (i.e., conditions of ample moisture) in the top 5 cm (King and Oliver, 1994; Masin et al., 2005). Increased germination may in part be related to the fact that crabgrass seed moisture content must increase to 38% to 50% before germination (King and Oliver, 1994).

Residue analysis. Prodiamine residues in soil 24 WAIT varied as a result of mowing height (Table 6). At NCSU, prodiamine soil residues at the 1.5-cm mowing height were greater than those detected at 3.8 cm. A similar response was observed at ETREC; however, it was not statistically significant ($P = 0.07$). We surmise that increasing the

Table 6. Mowing height-by-herbicide interactions proflaminate and pendimethalin soil residue data collected 24 weeks after treatment in Knoxville, TN (ETREC) and Raleigh, NC (NCSU) in 2013.^z

Mowing ht (cm)	Herbicide ^y	Rate ^x (g-ha ⁻¹)	Herbicide residue in soil	
			ETREC	NCSU
			----- (% of applied ^w) -----	
3.8	Pendimethalin	3,360	1.0	< LOD
	Proflaminate	1,680	3.3	2.8
1.5	Pendimethalin	3,360	1.1	< LOD
	Proflaminate	1,680	8.8	9.1
LSD _{0.05}			NS	3.3

^zSoil cores (2.5 × 2.5 × 2.0 cm) were collected from the center of treated plots at each location.

^yHerbicides were applied on 14 and 15 Mar. 2013 at Tennessee and NCSU, respectively. Proflaminate and pendimethalin residues in soil (0- to 2-cm depth) after application in Tennessee were 0.83 and 1.20 mg·kg⁻¹, respectively. At NCSU, proflaminate and pendimethalin residues in soil (0- to 2-cm depth) measured 3.00 and 6.60 mg·kg⁻¹ after application, respectively.

^xData are averaged over single and split applications. Split applications were applied initially and 8 weeks later.

^wLOD = level of detection.

ETREC = East Tennessee Research and Education Center–Plant Sciences Unit; NCSU = North Carolina State University Turf Field Laboratory; LSD = least significant difference; NS = nonsignificant.

bermudagrass canopy by mowing at a higher height of may limit proflaminate soil exposure at application. Although herbicide treatments were irrigated after application, it is likely that some was retained on the above-ground vegetation with greater amounts retained at the higher mowing height. In the case of proflaminate, if retained on the above-ground vegetation, it would be subject to photodegradation, perhaps decreasing its persistence (Senseman, 2007; Shaner, 2014). However, additional research is needed to confirm this theory. No difference in pendimethalin soil residue (1.1% or less of applied) was detected at NCSU or ETREC, regardless of mowing height. This may be attributable in part to pendimethalin having a shorter soil half-life than proflaminate (Senseman, 2007).

For financial reasons, the residue analysis was limited to two of the herbicides tested in field trials. However, responses indicate that differences in crabgrass control managed under different mowing heights may not be related to degradation of evaluated herbicides in soil. Rather, a higher bermudagrass canopy may reduce the amount of light that penetrates the bermudagrass canopy, thereby reducing crabgrass germination and subsequent growth. Reduced smooth crabgrass incidence in turf mowed at higher heights of cut has been reported previously in cool-season turfgrass (Debels et al., 2012; Dernoeden et al., 1998, 1993; Dunn et al., 1981; Hoyle et al., 2014; Jagschitz and Ebdon, 1985; Voigt et al., 2001). Debels et al. (2012) noted that although both mowing height and N application rate affect weed incidence in cool-season turfgrasses, increasing mowing height has a more dramatic effect on reducing weed abundance than augmenting fertilizer rates when clippings are returned after mowing.

Overall, we observed that increasing bermudagrass mowing height from 1.5 to 3.8 cm

increased the efficacy of several PRE herbicides for crabgrass control during a single year of a 2-year study. During the second year of the study, abnormally high rainfall at two locations may have diminished this response. Improved crabgrass control efficacy was likely the result of reduced PAR at the soil surface and not differential breakdown of applied herbicides at the 1.5- and 3.8-cm mowing heights based on our findings. Future research should explore effects of increasing bermudagrass mowing height on PAR required for crabgrass germination and growth.

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