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Effect of Reed-Sedge Peat Moss on Hybrid Bermudagrass Injury with Indaziflam and Prodiamine in Sand-Based Root Zones

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PRE herbicides have been reported to injure both the foliage and roots of hybrid bermudagrass turf established in sand culture. Research was conducted to evaluate the influence of reed-sedge peat moss (RSPM) on hybrid bermudagrass injury following PRE herbicide applications to plants established in sand culture. Washed sod plugs were established in mini-rhizotrons constructed with sand root-zones varying in organic carbon content (0.000, 0.003, 0.007, and 0.012 kg kg^{-1}). Herbicide treatments included indaziflam (35 and 52.5 g ai ha^{-1}) and prodiamine (840 g ai ha^{-1}). Significant foliar injury was only observed with indaziflam at 52.5 g ha^{-1}. When applied to plants in sand with no detectable (0.000 kg kg^{-1}) organic carbon, foliar injury measured 61% by 6 wk after treatment. Comparatively, injury with indaziflam at 52.5 g ha^{-1} was reduced by 40% with applications to plants established in sand with 0.007 kg kg^{-1} organic carbon. Root length, root length density, and root surface area were greatest in sand-based root zones with $\geq$ 0.007 kg kg^{-1} organic carbon regardless of herbicide treatment; however, only indaziflam (52.5 g ha^{-1}) and prodiamine-treated plants exhibited diminished root parameters relative to the nontreated check. Data in the current study illustrate that RSPM can affect above- and belowground injury following PRE herbicide applications to hybrid bermudagrass in sand root-zones.
Nomenclature: Indaziflam; prodiamine; hybrid bermudagrass, *Cynodon dactylon* (L.) Pers. × *Cynodon transvaalensis* Burtt-Davey.
Key words: Cellulose biosynthesis inhibitor, injury, mitotic inhibitor; organic matter, preemergence, tolerance, turfgrass.

Los herbicidas PRE han sido reportados como causantes del daño en el follaje y las raíces del césped bermuda híbrido en cultivo en arena. Se realizó una investigación para evaluar la influencia del musgo Sphagnum (RSPM) sobre el daño del césped bermuda híbrido después de aplicaciones de herbicidas PRE a plantas establecidas en cultivo en arena. Fragmentos lavados de estolones enraizados fueron establecidos en mini-rizotrones construidos con zonas de crecimiento radical de arena con un contenido variable de carbono orgánico (0.000, 0.003, 0.007, y 0.012 kg kg^{-1}). Los tratamientos con herbicidas incluyeron (indaziflam 35 y 52.5 g ai ha^{-1}) y prodiamine (840 g ai ha^{-1}). Se observó un daño foliar significativo con indaziflam a 52.5 g ha^{-1}. Cuando se aplicó a plantas en arena con carbono orgánico no detectable (0.000 kg kg^{-1}), el daño foliar fue 61% a 6 semanas después del tratamiento. Comparativamente, el daño con indaziflam a 52.5 g ha^{-1} fue reducido en 40% con aplicaciones a plantas establecidas en arena con 0.007 kg kg^{-1} carbono orgánico. Las máximas longitud, longitud-densidad y área superficial de las raíces se observaron en zonas de crecimiento radical de arena con $\geq$0.007 kg kg^{-1} carbono orgánico sin importar el tratamiento del herbicida. Sin embargo, solamente plantas tratadas con indaziflam (52.5 g ha^{-1}) y prodiamine exhibieron disminuciones en los parámetros de raíz en relación con el testigo no tratado. Los datos del presente estudio ilustran cómo RSPM puede afectar el daño del tejido aéreo y subterráneo en el césped bermuda híbrido posterior a aplicaciones de herbicidas PRE en las zonas de crecimiento radical en arena.

PRE herbicides are often applied to hybrid bermudagrass to control annual grassy weeds (Brosnan et al. 2011; Cooper et al. 1990; Johnson 1996; Perry et al. 2011). Two commonly used herbicidal mechanisms of action used for PRE weed control in hybrid bermudagrass are mitotic inhibition (MTI) and cellulose biosynthesis inhibition (CBI). Prodiamine is a dinitroaniline herbicide that inhibits mitosis by disrupting production of the microtubule protein tubulin in susceptible species (Senseman 2007; Tresch et al. 2005). Brosnan et al. (2011) reported that PRE applications of prodiamine at 0.84 kg ha^{-1} in spring effectively controlled (> 99%) of smooth crabgrass (*Digitaria ischaemum* Schreb.) in bermudagrass (*Cynodon dactylon* L. Pers.) turf throughout the summer in Tennessee and Georgia. Indaziflam is an alkylazine herbicide that inhibits cellulose biosynthesis in susceptible species (Myers et al. 2009); however, the precise site of action targeted by indaziflam has not been reported. Similar to prodiamine, PRE applications of indaziflam at 35, 52.5, and 70 g ha^{-1} have been shown to control smooth crabgrass > 95% (Brosnan et al. 2011). Indaziflam at rates of 30 to 60 g ha^{-1} have also been found to control annual bluegrass (*Poa annua* L.) > 93% through 28 wk after treatment (WAT) (Brosnan et al. 2012). Root absorption is required for weed control with indaziflam as soil-only and soil-plus-foliar applications have been found to control both smooth crabgrass and annual bluegrass greater than applications made to foliage alone (Brosnan and Breeden 2012).

Despite the effectiveness of these herbicides for controlling weeds, applications of MTI and CBI herbicides can injure both root and shoot tissue of desirable turfgrasses. Fishel and Coats (1994) reported that prodiamine applications at 1.1 kg ha^{-1} reduced bermudagrass root abundance and increased abnormal root morphology. Jones et al. (2013b) observed 68 to 89% reductions in root length density following indaziflam (35 g ha^{-1}) and prodiamine (840 g ha^{-1}) applications to

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hybrid bermudagrass in a sand-based root zone with no organic matter. When these same treatments were applied to hybrid bermudagrass established in silt loam, reductions were less pronounced (17 to 44% reduction compared to nontreated plants). Reductions in root length density with indaziflam reported by Jones et al. (2013b) were accompanied by substantial foliar injury (23 to 48%); however, this response was not observed on indaziflam-treated plants established in silt loam or with plants treated with prodiamine in either sand or silt loam. The researchers surmised that differences in foliar injury with indaziflam and prodiamine could be due to varying effects of these herbicides on hybrid bermudagrass root physiological function. In hydroponic culture, although both indaziflam and prodiamine reduced hybrid bermudagrass root biomass compared to a nontreated control, foliar magnesium and manganese content in indaziflam-treated plants measured lower than the nontreated control whereas prodiamine did not (Jones et al. 2013a). This response suggests that these herbicides may differentially affect translocation of micronutrients involved in photosynthesis from root to shoot tissue. Reductions in magnesium and manganese would compromise photosynthesis as magnesium is a central component of chlorophyll, contributing electrons to photosystem II (PSII) after absorbing photons, whereas manganese is a catalyst for the Hill reaction, oxidizing water molecules to replace electrons lost to PSII from photon excitation (Cheniae and Martin 1969; Taiz and Zeiger 2010).

Numerous studies have demonstrated that organic matter content is highly correlated to PRE herbicide activity. Harrison et al. (1976) evaluated oat (*Avena sativa* L. 'Carolee') phytotoxicity with five different herbicides (atrazine, chloramben, fluometuron, propachlor, and trifluralin) applied PRE in 10 different North Carolina soils and reported that herbicidal activity was significantly correlated (mean of $r = 0.78$ to 0.80 for all five herbicides) with soil organic matter content. Activity of triazine herbicides applied PRE has been linked with soil organic matter content (Harrison et al. 1976; Rahman and Matthews 1979). In six loam- or clay-based coastal soils, with organic matter ranging from 1.0 to 3.8%, Blumhorst et al. (1990) reported significant associations ($r = 0.66$ to 0.84) between soil organic matter content and efficacy of atrazine, cyanazine, alachlor, metolachlor, and pendimethalin for PRE weed control in corn (*Zea mays* L.). The researchers calculated that the herbicide rates required to achieve 80% weed control were 1.4 to 2.9 times greater in soils with 3.8% organic matter compared to 1% organic matter. Alonso et al. (2011) evaluated sorption of indaziflam in four oxisol and three mollisol soils and reported that sorption in both soil orders was positively correlated to soil organic carbon content ($r = 0.67$ to 0.99). Although indaziflam is classified as a weak acid (pKa = 3.5) and would be primarily anionic in the oxisol soils tested (pH ranging from 5.4 to 6.2), the researchers suggested that the high degree of sorption observed may be an effect of the triazinediamide group on the indaziflam structure interacting with organic carbon content of the soils. Sorption coefficients ($K_{f,oc}$) in mollisols were lower (498 to 602) than those measured in oxisols (415 to 1,428). Although the mollisol soils tended to be higher in organic carbon (1.1 to 2.5%) than the oxisols (0.5 to 2.2%), they measured much higher in soil pH (6 to 8.3).

Variable root and shoot injury has been reported following indaziflam and prodiamine applications to hybrid bermudagrass established in sand (0% organic matter) and silt loam (1.4% organic matter) soils (Jones et al. 2013b). Increasing organic matter content of sand root-zones may lead to greater herbicide sorption and reduce the likelihood for root or shoot injury. However, data describing the impacts of organic matter content on these responses are limited. Thus, the objective of this study was to evaluate the influence of organic matter content on hybrid bermudagrass injury following PRE herbicide applications to plants established in sand culture.

Materials and Methods

Research was conducted in the summer of 2012 at the University of Tennessee (Knoxville, TN; 35.94, –83.94). 'Tifway' hybrid bermudagrass was established from washed sod in mini-rhizotrons using methods similar to those previously reported by other researchers (Brosnan et al. 2010; Jones et al. 2013b). Clear polyethylene tubes (3 mm thickness, 3.8 cm outside diam, 30 cm length) were constructed with a heat sealer and small holes were made in each tube to allow for drainage. Tubes were filled with either 100% rounded silica sand (US Silica, Berkeley Springs, WV) containing 0 kg kg^{-1} organic carbon (by weight) or one of three sands uniformly blended with finely graded reed-sedge peat moss (RSPM) (Peat Inc, Elk River, MN 55330). RSPM was chosen as the organic matter source in that it is commonly used to amend sand-based root zones prior to turfgrass establishment (Hummel 2000). Laboratory testing according to ASTM D-2974 indicated that this RSPM source contained 88% organic carbon and measured 42% in moisture content (ASTM International 2012). Three volumetric sand-to-RSMP ratios were evaluated: (1) a 95 : 5 ratio containing 0.003 kg kg^{-1} organic carbon; (2) aj 80 : 20 ratio containing 0.007 kg kg^{-1} organic carbon; and (3) a 60 : 40 ratio containing 0.012 kg kg^{-1} organic carbon. Organic carbon content (kg kg^{-1}) of each root zone was determined following the loss-on-ignition procedures of ASTM F1647 prior to mini-rhizotron construction (ASTM International 2011). All sands conformed to United States Golf Association particle size diameter specifications (0%, > 2.0 mm; 0.9%, 1.0 to 2.0 mm; 25.8%, 0.5 to 1.0 mm; 55.7%, 0.25 to 0.5 mm; 13.8%, 0.15 to 0.25 mm; 3.6%, 0.05 to 0.15 mm). Soil pH, nutrient content, and cation exchange capacity (CEC) of each root zone are presented in Table 1.

Each root zone was poured and packed into the mini-rhizotron at a bulk density of 1.4 Mg m^{-3}. A polyvinyl chloride (PVC) pipe was cut to 30 cm and a bolt was positioned in the lower end to support each polyethylene tube. The PVC pipe formed a sleeve around the sand-filled tube after insertion. Tubes were placed in a frame at a 30° angle from horizontal to monitor gravitropic root growth along the polyethylene liner of each tube.

Day and evening air temperatures in each of the two glasshouses used averaged 31/23 and 29/25 C under conditions of natural light. Plant nutrients in each experiment were supplied weekly at a rate of 49 kg N ha^{-1} with a complete fertilizer (20-20-20; Howard Johnson's Enterprises,

Table 1. Soil chemical properties for sand-based root zones used in mini-rhizotron experiments conducted in glasshouses at the University of Tennessee (Knoxville, TN; 35.94, −83.94 during 2012. All data were collected at the University of Tennessee Soil, Plant, and Pest Center (Nashville, TN).

Organic carbon[ab]	CEC	pH[b]	P[b]	K[b]	Ca[b]	Mg[b]
$kg\ kg^{-1}$	$meq\ 100\ g^{-1}$		$kg\ ha^{-1}$			
0.000	0.14	6.2	5.6	5.6	69.4	12.3
0.003	0.43	5.3	5.6	9.0	175.8	25.8
0.007	0.50	5.2	4.5	7.8	207.2	26.9
0.012	0.42	4.9	5.6	7.8	241.9	26.9

[a] Sand root-zones were volumetrically blended with varying amounts of reed-sedge peat moss (Short Mountain Silica, Mooresburg, TN).

[b] Organic carbon content determined according to ASTM F-1647 (ASTM International 2011).

Inc, Milwaukee, WI) and mowed daily at a height of 3.8 cm using hand shears with clippings returned. Irrigation was used to promote active hybrid bermudagrass growth.

Plants established in each mini-rhizotron were treated with one of two different herbicides 2 wk after transplanting. Rooting depth at application ranged from 10 to 15 cm and was determined using previously published methods (Brosnan et al. 2010; Jones et al. 2013b). The length of the longest subtending root from the crown that was visible along the sidewall of each polyethylene tube was measured on the day of herbicide application. Herbicide treatments included indaziflam (Specticle 20 WSP, Bayer Environmental Sciences, Research Triangle Park, NC) at 35 and 52.5 g ha^{-1} and prodiamine (Barricade 65 WG, Syngenta Crop Protection, Greensboro, NC) at 840 g ha^{-1}. Indaziflam and prodiamine rates were selected according to label directions (Anonymous 2010, 2012). Differences in above- and belowground injury have been reported with these indaziflam and prodiamine rates applied to hybrid bermudagrass in sand culture (Jones et al. 2013b). A nontreated check was also included at each organic carbon level for comparison. Treatments were applied with a CO_2-powered boom sprayer calibrated to deliver 281 L ha^{-1} utilizing flat-fan nozzles (8002VS; Spraying Systems Co., Roswell, GA) at 124 kPa. Treatments were watered in to an approximately 10-mm depth after application.

Hybrid bermudagrass injury was visually assessed weekly using a 0 (i.e., no injury) to 100% (i.e., plant death) scale relative to nontreated plants. At 6 WAT, roots were washed free of media and excised as close to the crown as possible. WinRhizo software (Regent Instruments, Quebec, Canada) was used to characterize root length (cm), root surface area (cm^2), and root length density ($cm\ cm^{-3}$) according to methods of Brosnan et al. (2010) and Jones et al. (2013b). Root length density is defined as the length of roots per volume of soil and has been reported to provide the most utility in mini-rhizotron experiments evaluating root growth (Merrill and Upchurch 1994).

The experimental design was a randomized complete block, four-by-four factorial, with four replications. Two experimental runs were conducted in individual glasshouses. Factors included four sand root-zones varying in organic carbon content (0.000, 0.003, 0.007, and 0.012 kg kg^{-1}) and four herbicide treatments (indaziflam at 35 and 52.5 g ha^{-1}; prodiamine at 840 g ha^{-1}; nontreated check). All data were subjected to ANOVA in SAS (SAS Institute Inc., Cary, NC) using the appropriate expected mean square values described by McIntosh (1983). Fisher's Protected LSD values are reported for mean comparisons at the ($\alpha \leq 0.05$) level.

Results and Discussion

No significant treatment-by-experimental run interactions were detected; therefore, data from each experimental run were combined.

Hybrid Bermudagrass Injury. Significant root zone-by-herbicide interactions were detected in hybrid bermudagrass injury data (Table 2) ($P < 0.001$). No differences in foliar injury were observed between prodiamine and the 35 g ha^{-1} rate of indaziflam regardless of root zone organic carbon content. Foliar injury with these treatments ranged from 0 to 12% from 1 to 6 WAT and was not greater than the nontreated check (which exhibited no foliar injury symptoms) at any time. Jones et al. (2013b) reported a similar response with prodiamine applications to plants growing in both silt loam and a sand root-zone with no organic carbon. Jones et al. (2013b) noted greater foliar injury with the 35 g ha^{-1} rate of indaziflam than was observed herein (25 to 47%). The researchers treated plants varying in rooting depth from 5 to 15 cm and observed greater injury at shallower depths. In the current study, rooting depth at application ranged from 10 to 15 cm. Excluding shallower rooted plants could have reduced overall hybrid bermudagrass injury with indaziflam at 35 g ha^{-1}.

In the current study, significant hybrid bermudagrass foliar injury was observed with the 52.5 g ha^{-1} rate of indaziflam (Table 2). Injury was characterized by a curling of new growth, reddening of leaf tissue, and eventual necrosis similar to previous reports (Jones et al. 2013a). In a sand root-zone with no organic carbon (0.000 kg kg^{-1}), injury ranged from 6 to 61% from 1 to 6 WAT. An increase to 0.003 kg kg^{-1} organic carbon reduced hybrid bermudagrass injury at all rating dates except at 4 WAT. Increasing organic carbon content to 0.007 and 0.012 kg kg^{-1} reduced injury compared to 0.000 kg kg^{-1} regardless of rating date. For example, at 3 WAT in a sand root-zone with no organic carbon, indaziflam at 52.5 g ha^{-1} injured hybrid bermudagrass 52%. When this treatment was applied to plants established in a sand root-zone with 0.003 kg kg^{-1} organic carbon, injury was reduced to 32%; increasing organic carbon content to 0.007 and 0.012 kg kg^{-1} reduced injury to 14 and 8%, respectively. Increasing organic content from 0.003 to 0.007 kg kg^{-1} reduced hybrid bermudagrass injury on all but one evaluation date. On no date were significant reductions in hybrid bermudagrass injury observed when organic carbon increased from 0.007 to 0.012 kg kg^{-1}. This response suggests a minimum organic carbon content of 0.007 kg kg^{-1} may be required to reduce hybrid bermudagrass injury with indazi-

Table 2. Root zone-by-herbicide treatment interactions on hybrid bermudagrass [*C. dactylon* (L.) Pers. × *C. transvaalensis* Burtt-Davey, cv. 'Tifway'] injury during two glasshouse experiments conducted in Knoxville, TN (35.94, –83.94) during the summer of 2012.

			Hybrid bermudagrass injury[a]					
Organic carbon[b]	Herbicide	Rate	1 WAT[b]	2 WAT	3 WAT	4 WAT	5 WAT	6 WAT
$kg\ kg^{-1}$		$g\ ha^{-1}$	%					
0.000	Indaziflam	35	1	6	4	6	8	5
		52.5	6	44	52	60	61	61
	Prodiamine	840	2	9	5	8	12	10
0.003	Indaziflam	35	0	4	1	4	4	4
		52.5	1	26	32	53	47	48
	Prodiamine	840	0	6	5	9	9	9
0.007	Indaziflam	35	0	2	1	3	1	4
		52.5	1	9	14	20	19	21
	Prodiamine	840	1	5	3	6	6	4
0.012	Indaziflam	35	0	4	1	6	4	4
		52.5	0	11	8	14	11	14
	Prodiamine	840	0	3	3	2	5	10
		$LSD_{0.05}$	2	6	7	11	12	12

[a] Hybrid bermudagrass injury was assessed weekly using a 0 (no injury) to 100 (plant death) visual scale relative to a nontreated check.

[b] Sand root-zones were blended with varying amounts of reed-sedge peat moss (Short Mountain Silica). Organic carbon content determined according to ASTM F-1647 (ASTM International 2011).

[c] Abbreviation: WAT, weeks after treatment.

flam at 52.5 g ha^{-1}. However, further field testing is needed to validate this theory.

Root Morphology. Root morphological data (i.e., root length, root surface area, and root length density) varied due to root zone and herbicide treatment; however, no root zone-by-herbicide interactions were detected ($P = 0.2803$, 0.2791, and 0.2812, respectively); therefore, means were combined across herbicides. Root length, root surface area, and root length density were lowest on sand root-zones with ≤ 0.003 kg kg^{-1} organic carbon; no significant differences were detected between the 0.000 and 0.003 kg kg^{-1} root zones at any time (Table 3). Root length, root surface area, and root length density values were greatest in sand root-zones with ≥ 0.007 kg kg^{-1} organic carbon and differences were not detected between root zones containing 0.007 and 0.012 kg kg^{-1}.

Root morphological data varied due to herbicide treatment (Table 4). No differences in root length, root surface area, and root length density were detected between indaziflam at 35 g ha^{-1} compared to the nontreated check. Averaged over the four root zones, prodiamine and indaziflam at 52.5 g ha^{-1} reduced root length, root surface area, and root length density by 50 to 65%. For each root parameter, indaziflam at 52.5 g ha^{-1} resulted in a greater reduction than prodiamine. This response is similar to Jones et al. (2013b), who reported root length density reductions of 77 to 83% with indaziflam at 52.5 g ha^{-1} compared to 67 % for prodiamine in a sand root-zone with no organic carbon.

Data in the current study illustrate that soil organic carbon content and application rate affect indaziflam injury potential to hybrid bermudagrass grown in sand-based root zones. Increasing organic carbon content from 0.000 to 0.007 kg kg^{-1} reduced hybrid bermudagrass injury with indaziflam at 52.5 g ha^{-1} on every evaluation date. These increases in organic carbon content also minimized reductions in root length, root surface area, and root length density. Within the limitations of these experiments, our data show no benefit to having organic carbon in excess of 0.007 kg kg^{-1}.

Decreased indaziflam injury with increasing organic carbon content supports the work of Alonso et al. (2011) who reported positive correlations between sorption values and organic carbon content in several soils. Foliar injury and root reductions in our study were lowest in sands containing ≥ 0.007 kg kg^{-1} organic carbon. These sand root-zones also measured 4.9 to 5.2 in soil pH, conditions that would not be considered favorable for indaziflam sorption. Alonso et al.

Table 3. Effect of organic matter content on hybrid bermudagrass [*C. dactylon* (L.) Pers. × *C. transvaalensis* Burtt-Davey, cv. 'Tifway'] root morphology during two glasshouse experiments conducted in Knoxville, TN (35.94, –83.94) during the summer of 2012. Means were averaged over four herbicide treatments (indaziflam at 35 and 52.5 g ha^{-1}, prodiamine at 840 g ha^{-1}, nontreated check).

Organic carbon[a]	Root length	Root surface area	Root length density
$kg\ kg^{-1}$	cm	cm^2	$cm\ cm^{-3}$
0.000	1,050	112	1.10
0.003	939	102	0.98
0.007	1,215	132	1.27
0.012	1,359	144	1.42
$LSD_{0.05}$	175	21	0.18

[a] Sands were blended with reed-sedge peat moss (Short Mountain Silica). Organic carbon content determined according to ASTM F-1647 (ASTM International 2011).

Table 4. Effect of herbicide treatment on hybrid bermudagrass [*C. dactylon* (L.) Pers. × *C. transvaalensis* Burtt-Davey, cv. 'Tifway'] root morphology during two glasshouse experiments conducted in Knoxville, TN (35°56′N) during the summer of 2012. Means were averaged over four root zones containing 0.000 to 0.012 kg kg^{-1} organic carbon.

Herbicide	Rate	Root length	Root surface area	Root length density
	$g\ ha^{-1}$	cm	cm^2	$cm\ cm^{-3}$
Indaziflam	35	1,582	173	1.65
Indaziflam	52.5	615	60	0.64
Prodiamine	840	794	86	0.83
Nontreated check		1,574	172	1.64
$LSD_{0.05}$		176	21	0.18

(2011) also reported high indaziflam sorption at soil pH values expected to be unfavorable for sorption (based on the dissociation constant of indaziflam) and surmised that this was due to the triazine amide group present on the indaziflam molecule. Additionally, the researchers noted that clay mineralogy can affect indaziflam sorption when the clay-to-organic carbon ratio in soil is greater than 25. Although increases in clay content would positively affect CEC, these values were not reported by Alonso et al. (2011). In the current study, increased organic carbon content of the sand root-zones tested reduced pH values to levels unfavorable for indaziflam sorption (4.9 to 5.2) and concomitantly increased CEC values from 0.14 meq 100 g^{-1} in a sand with no organic carbon to 0.42 to 0.50 meq 100 g^{-1}. These changes were associated with reduced above- and belowground hybrid bermudagrass injury. These responses would suggest that CEC affects indaziflam activity in sand culture to a greater extent than soil pH; however, additional studies are needed to confirm this theory given the narrow range of soil pH and CEC values evaluated in this work.

Our study was limited in that it was conducted in mini-rhizotron culture in glasshouses with RSPM uniformly blended throughout a 30-cm profile. The decision was made to ensure uniformity between mini-rhizotrons of a single treatment. This even distribution of RSPM would not likely be seen in a field situation. In a field situation, organic carbon content would be greatest in the uppermost portion of the soil profile near the soil–turf interface. Future studies looking at the effects of organic carbon on herbicide activity should address this issue. Lastly, RSPM was the only organic matter source used in this study. Future research should evaluate effects of PRE herbicides on hybrid bermudagrass established in sand culture with different sources of organic carbon.

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