

SHORT COMMUNICATION

Turfgrass Establishment and Maintenance

Response of JSC 2-21-18 (Iron Cutter[®]) hybrid bermudagrass to postemergence herbicides and plant growth regulators

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Abstract

A field study was conducted in Athens, GA, to evaluate JSC 2-21-18 (Iron Cutter[®]) hybrid bermudagrass (*Cynodon dactylon* (L.) Pers. × *C. transvaalensis* Burt Davy) response to postemergence herbicides (topramezone + metribuzin, thiencazone-methyl + foramsulfuron + halosulfuron, thiencazone-methyl + iodosulfuron + dicamba, 2,4-D + triclopyr + dicamba + pyraflufen, foramsulfuron, sulfosulfuron, monosodium methanearsonate, quinclorac, and 2,4-D + mecoprop + dicamba + carfentrazone). Thiencazone-methyl + foramsulfuron + halosulfuron, thiencazone-methyl + iodosulfuron + dicamba, monosodium methanearsonate, and 2,4-D + mecoprop + dicamba + carfentrazone resulted in similar turfgrass color (TC), turfgrass quality (TQ), and normalized difference vegetation index (NDVI) as the non-treated check, regardless of rating date. Topramezone + metribuzin and 2,4-D + triclopyr + dicamba + pyraflufen were most injurious, causing significantly lower TC, TQ, and NDVI than the non-treated check 3 weeks after treatment (WAT). Decreases in TC were also observed in response to quinclorac, sulfosulfuron, and foramsulfuron 3 WAT; however, recovery from quinclorac and sulfosulfuron was reported 4 WAT. A second study examined JSC 2-21-18 response to trinexapac-ethyl (TE), prohexadione calcium (PC), and TE + PC applied every 2 weeks. All treatments resulted in higher TC, TQ, and NDVI than the non-treated check 40 days after initial treatment (DAIT), except TE at 96 g ai ha⁻¹ with respect to TQ. The highest TC, TQ, and NDVI was observed in response to PC at 460 g ai ha⁻¹. At 84 DAIT, TE + PC resulted in the greatest percent growth inhibition (GI) (46%) followed by PC (41%), regardless of rate, while TE only resulted in % GI of 31%–32%. In general, a greater increase in aesthetics and inhibition was observed in response to PC than TE.

1 | INTRODUCTION

Hybrid bermudagrass [*Cynodon dactylon* (L.) Pers. × *C. transvaalensis* Burt Davy] is the most widely used warm-

season turfgrass for home lawns, sports fields, and golf courses throughout tropical and subtropical regions of the United States. Quick establishment through the spread of aggressive rhizomes and stolons aids in both soil stabilization and erosion control, as well as a high recuperative capacity following excessive wear and traffic (McCarty & Miller, 2002; Pornaro et al., 2019). Fine leaf texture, dark green color, and the production of a dense, low-growing canopy make

Abbreviations: GI, growth inhibition; NDVI, normalized difference vegetation index; PC, prohexadione calcium; TC, turfgrass color; TE, trinexapac-ethyl; TQ, turfgrass quality; WAT, weeks after initial treatment; WAT, weeks after treatment.

bermudagrass the ideal selection for a home lawn, while an ability to tolerate a wide range of soil conditions and environmental stress allows for use as a utility turf (Christians et al., 2016; Turgeon & Kaminski, 2019). Although Tifway hybrid bermudagrass continues to be one of the most popular cultivars, extensive breeding efforts have led to improvements in aesthetic and physiological traits of several new varieties (Henry, 2023). JSC 2-21-18 (Iron Cutter®) hybrid bermudagrass was released under its experimental breeding code from Oklahoma State University in 2019 with discernable improvements in drought, traffic, and cold tolerance (Taliaferro, 2020); however, limited information is available regarding the response of JSC 2-21-18 to postemergence herbicides and plant growth regulators.

Intense management practices and high levels of inputs are often required to produce a continuous, uniform hybrid bermudagrass playing surface for both sports fields and golf courses. Postemergence herbicides are often used to control annual weed escapes or problematic perennial weeds. Although most active ingredients are selective and target both grass and broadleaf weeds, phytotoxicity can occur under adverse environmental conditions or due to the genetic sensitivity of specific cultivars. Reductions in turfgrass aesthetics and plant function following herbicide application can adversely impact turfgrass performance and health. Plant growth regulators are used to increase canopy density, enhance turfgrass color (TC), improve environmental stress tolerance, and reduce clipping production (Fry & Huang, 2004). However, not all bermudagrasses respond similarly to plant growth regulator applications. McCullough et al. (2005) reported a wide range of growth regulation of bermudagrass cultivars in response to sequential trinexapac-ethyl (TE) applications. The greatest amount of growth reduction was observed in P18 (MiniVerde®) ultradwarf hybrid bermudagrass (69%) with the least reported in TifEagle (46%) (McCullough et al., 2005). Unfortunately, new hybrid bermudagrass cultivars often reach the market without ever having substantial testing with respect to their response to management inputs. Therefore, the objective of our research was to examine the response of JSC 2-21-18 hybrid bermudagrass to postemergence herbicides and plant growth regulators.

2 | MATERIALS AND METHODS

2.1 | Postemergence herbicides

Research was conducted at the Athens Turfgrass Research and Education Center (ATREC; 33°54'22.0104" N, 83°21'56.0484" E; 194 m above sea level) in Athens, GA, during the summer of 2021. The trial was located on a newly sodded stand of JSC 2-21-18 hybrid bermudagrass (1-month old) maintained at 3.8 cm with a Honda twin-blade walk-behind rotary mower (American Honda Motor Com-

Core Ideas

- Topramezone + metribuzin and 2,4-D + triclopyr + dicamba + pyraflufen were most injurious.
- Color, quality, and normalized difference vegetation index of JSC 2-21-18 bermudagrass was greatest with prohexadione calcium (PC).
- PC regulated JSC 2-21-18 hybrid bermudagrass more than trinexapac-ethyl.

pany). The soil type was a Cecil clay loam (fine, kaolinitic, thermic Typic Kanhapludults) with a soil pH of 5.8 and organic matter content of 1.5%. Herbicide treatments were selected due to previous concerns with phytotoxicity or due to their common use for weed control in turfgrass systems (Table 1). All herbicide rates were at or below maximum labeled amounts for hybrid bermudagrass turf and chosen for the control of problematic weeds. Treatments were initiated on July 15, 2021 and were applied with a CO₂-powered backpack sprayer equipped with XR8003VS nozzles (Teejet Spraying Systems Co.) calibrated to deliver 375 L ha⁻¹ at 221 kPa. Nutrition was supplied via complete fertilizer (18N-0P₂O₅-1K₂O) (Greene County Fertilizer Company) at a rate of 24.5 kg N ha⁻¹ 1 week prior to trial initiation. Irrigation was supplied through an overhead irrigation system calibrated to deliver approximately 3.8 cm of water per week. Plots (1.5 m × 1.5 m) were arranged in a randomized complete block design with four replications. Visual ratings of TC and turfgrass quality (TQ) were recorded weekly on a scale of 1–9 with a rating ≥6 considered acceptable (Krans & Morris, 2007). Normalized difference vegetation index (NDVI) was recorded weekly with a Field Scout CM 1000 NDVI chlorophyll meter (Spectrum Technologies Inc.). An average of three readings were obtained per plot per rating date.

2.2 | Plant growth regulators

A field experiment was conducted at the ATREC in Athens, GA, during the summer of 2021. Research was conducted on a 1-year-old JSC 2-21-18 hybrid bermudagrass stand maintained at 1.3 cm with a Toro Greensmaster 1600 walk-behind reel mower (The Toro Company). The soil type was a Cecil clay loam (fine, kaolinitic, thermic Typic Kanhapludults) with a soil pH of 5.7 and organic matter content of 1.3%. Plant growth regulator treatments were initiated on July 15, 2021 with sequential applications made every 2 weeks for a total of six applications throughout the length of the trial. Treatments consisted of TE at 96 (recommended for Tifway golf course fairways) and 126 g ai ha⁻¹, prohexadione calcium (PC) at 235 and 460 g ai ha⁻¹ (this is the range recommended for hybrid bermudagrass golf course fairways and roughs), and

TABLE 1 Postemergence herbicide treatments applied to JSC 2-21-18 hybrid bermudagrass in Athens, GA.

Herbicide treatment ^a	Active ingredient	Rate (g ai ha ⁻¹) ^b
Non-treated check	N/A	N/A
Pylex™ + Sencor®	Topramezone + metribuzin	32 + 183
Tribute Total® ^c	Thiencarbazon + foramsulfuron + halosulfuron ^c	136
Celsius®	Thiencarbazon + iodosulfuron + dicamba	233
4-Speed® XT	2,4-D + triclopyr + dicamba + pyraflufen	1200
Revolver®	Foramsulfuron	15
Certainty®	Sulfosulfuron	66
MSMA	Monosodium methanearsonate	2300
Drive® XLR8	Quinclorac	830
SpeedZone® Southern	2,4-D + mecoprop + dicamba + carfentrazone	227

Abbreviation: N/A, not applicable.

^aHerbicides were applied with a CO₂-powered backpack sprayer equipped with XR8003VS nozzles calibrated to deliver 375 L ha⁻¹ at 221 kPa.

^bHerbicide maximum labeled rates (g ai ha⁻¹) on hybrid bermudagrass: topramezone, 49; metribuzin, 564; thiencarbazon + foramsulfuron + halosulfuron, 168; thiencarbazon + iodosulfuron + dicamba, 233; 2,4-D + triclopyr + dicamba + pyraflufen, 1606; foramsulfuron, 59; sulfosulfuron, 105; monosodium methanearsonate, 2244; quinclorac, 841; and 2,4-D + mecoprop + dicamba + carfentrazone, 505.

^cMethylated seed oil was added to thiencarbazon + foramsulfuron + halosulfuron, thiencarbazon + iodosulfuron + dicamba, foramsulfuron, and quinclorac at 0.5% v/v, while a nonionic surfactant at 0.25% v/v was added to sulfosulfuron.

TE at 96 g ai ha⁻¹ + PC at 235 g ai ha⁻¹ (Anonymous, 2015a, 2018a). A non-treated check was included for comparison. Plant growth regulators were applied with a CO₂-powered backpack sprayer equipped with XR8003VS nozzles (Tee-jet Spraying Systems Co.) calibrated to deliver 375 L ha⁻¹ at 221 kPa. Nutrition was supplied via complete fertilizer (18N-2P₂O₅-4K₂O) (Helena Professional Products) at a rate of 24.5 kg N ha⁻¹ 1 week prior to trial initiation. Irrigation was supplied through an overhead irrigation system calibrated to deliver approximately 3.8 cm of water per week. Plots measuring 1.5 m × 1.5 m were arranged in a randomized complete block design with four replications. Visual ratings of TC and TQ along with NDVI measurements were collected as previously described. The site was mowed weekly; however, turfgrass clippings were only collected every 2 weeks. A perimeter pass was mowed around each plot leaving approximately 1.0 m × 1.0 m of non-mowed turf. This area was mowed separately for each plot with clippings transferred from the mower bucket into individual paper bags using a brush. Clippings were dried in an oven for 48 h at 110°C and weighed to determine biomass (g). Percent growth inhibition (% GI) was calculated by comparing clippings within treated plots to the non-treated check within the same replication.

2.3 | Data analysis

Data were subjected to analysis of variance using PROC GLM in SAS (version 9.4, SAS Institute Inc.). Treatment and rating dates were fixed variables, while blocks were a random variable. Treatment means were separated using Fisher's protected least significant difference test at $\alpha = 0.05$.

3 | RESULTS AND DISCUSSION

3.1 | Postemergence herbicides

Thiencarbazon-methyl + foramsulfuron + halosulfuron, thiencarbazon-methyl + iodosulfuron + dicamba, monosodium methanearsonate, and 2,4-D + mecoprop + dicamba + carfentrazone resulted in similar TC, TQ, and NDVI as the non-treated check, regardless of rating date (Table 2). Similarly, Busey (2004) reported that monosodium methanearsonate (MSMA) at 2430 g ai ha⁻¹ caused no significant injury to a Tifway hybrid bermudagrass rough. Although Henry et al. (2007) observed injury ($\leq 15\%$) to a Common (*C. dactylon*) rough in response to MSMA at 2500 g ai ha⁻¹, recovery occurred by 2 weeks after initial treatment (WAIT). Topramezone + metribuzin and 2,4-D + triclopyr + dicamba + pyraflufen were most injurious to JSC 2-21-18 hybrid bermudagrass in our research. At 3 weeks after treatment (WAT), TC, TQ, and NDVI ratings for topramezone + metribuzin were 4.5, 5.9, and 0.7, respectively, while the same parameters for 2,4-D + triclopyr + dicamba + pyraflufen were 5.1, 5.1, and 0.75, respectively. At 4 WAT, hybrid bermudagrass injury in response to topramezone + metribuzin recovered to similar levels as the non-treated check; however, TC, TQ, and NDVI in response to 2,4-D + triclopyr + dicamba + pyraflufen were still significantly lower than the non-treated check (Table 2). Kerr et al. (2019) reported greater turfgrass injury ($>50\%$) to Tifway hybrid bermudagrass in response to topramezone alone at 12.3 g ai ha⁻¹ or in combination with metribuzin at 420 g ai ha⁻¹, but ratings were conducted 2 WAT. Similar to our results, Lindsey et al. (2019) observed 97% green color of Common

TABLE 2 Turfgrass color, turfgrass quality, and normalized difference vegetation index (NDVI) of JSC 2-21-18 hybrid bermudagrass in response to postemergence herbicides applied in Athens, GA.

Herbicide treatment ^b	Active ingredient	Turfgrass color ^a		Turfgrass quality		NDVI	
		3 WAT	4 WAT	3 WAT	4 WAT	3 WAT	4 WAT
Non-treated check	N/A	7.3a ^c	7.0ab	6.9a	6.9a	0.85a	0.90a
Pylex + Sencor	Topramezone + metribuzin	4.5e	7.3a	5.9bc	6.8ab	0.70d	0.87ab
Tribute Total ^d	Thiencarbazon + foramsulfuron + halosulfuron ^b	6.4abc	6.9abc	6.3ab	6.6ab	0.82ab	0.88ab
Celsius	Thiencarbazon + iodosulfuron + dicamba	6.4abc	7.1a	6.5ab	6.8ab	0.82ab	0.89ab
4-Speed XT	2,4-D + triclopyr + dicamba + pyraflufen	5.1de	6.4c	5.1c	6.3b	0.76c	0.85b
Revolver	Foramsulfuron	6.1bc	6.5c	6.4ab	6.6ab	0.81abc	0.87ab
Certainty	Sulfosulfuron	6.0bcd	6.8abc	6.5ab	6.6ab	0.80abc	0.87ab
MSMA	Monosodium methanearsonate	6.6ab	7.0ab	6.5ab	7.0a	0.81abc	0.86ab
Drive XLR8	Quinclorac	5.5cd	6.8abc	6.1ab	6.6ab	0.79bc	0.87ab
SpeedZone Southern	2,4-D + mecoprop + dicamba + carfentrazone	6.8ab	6.9abc	6.6ab	7.0a	0.82ab	0.89ab
LSD (0.05)		1.0	0.6	0.09	0.06	0.06	0.04

Abbreviations: LSD, least significant difference; N/A, not applicable; normalized difference vegetation index; WAT, weeks after treatment.

^aVisual ratings of turfgrass color and turfgrass quality were recorded on a scale of 1–9 with a rating of 6 considered acceptable. NDVI was measured with a Field Scout CM 1000. An average of three measurements was taken to represent each plot at each rating date.

^bHerbicides were applied with a CO₂-powered backpack sprayer equipped with XR8003VS nozzles calibrated to deliver 375 L ha⁻¹ at 221 kPa.

^cMeans within a column followed by the same lowercase letter are not significantly different according to Fisher's protected LSD test at $\alpha = 0.05$.

^dMethylated seed oil was added to thiencarbazon + foramsulfuron + halosulfuron, thiencarbazon + iodosulfuron + dicamba, foramsulfuron, and quinclorac at 0.5% v/v, while a nonionic surfactant at 0.25% v/v was added to sulfosulfuron.

bermudagrass pots 21 days after spraying in response to topramezone + metribuzin (11 + 101 g ai ha⁻¹). Boyd et al. (2021) observed 29% phytotoxicity to Tifway hybrid bermudagrass 2 WAIT following topramezone at 13 g ai ha⁻¹ with recovery observed by 4 WAIT, while Cox et al. (2017) also reported 15%–18% injury on Tifway, Latitude 36 Turf Bermudagrass, and Northbridge Turf Bermudagrass hybrid bermudagrass during the 4-week period following topramezone at 6 and 12 g ai ha⁻¹. Topramezone at 32 g ai ha⁻¹ was evaluated in our research since that is the highest labeled rate for the control of several important turfgrass weeds: goosegrass [*Eleusine indica* (L.) Gaertn.], large crabgrass [*Digitaria sanguinalis* (L.) Scop.], smooth crabgrass [*Digitaria ischaemum* (Schreb.) Muhl.], and broadleaf signalgrass [*Urochloa platyphylla* (Munro ex C.Wright) R.D.Webster [syn. *Brachiaria platyphylla* (Munro ex C.Wright) Nash]] (Anonymous, 2018b). Decreases in hybrid bermudagrass TC in our research were also observed in response to quinclorac (5.5), sulfosulfuron (6.0), and foramsulfuron (6.1) 3 WAT. However, hybrid bermudagrass TC following quinclorac and sulfosulfuron applications recovered by 4 WAT, while TC in response to foramsulfuron still remained significantly lower than the non-treated check. McCullough et al. (2012) only reported 4%–7% phytotoxicity on an unknown cultivar

from an undefined *Cynodon* Rich. species 3 and 4 weeks after foramsulfuron at 4 g ai ha⁻¹. No significant injury to a Tifway hybrid bermudagrass rough was reported by Busey (2004) following applications of foramsulfuron at 3–5 g ai ha⁻¹; however, both of these studies used foramsulfuron rates substantially lower than those applied in our trial (15 g ai ha⁻¹).

3.2 | Plant growth regulators

All treatments resulted in higher TC, TQ, and NDVI than the non-treated check 40 days after initial treatment (DAIT), except TE at 96 g ai ha⁻¹ with respect to TQ (Table 3). The highest TC, TQ, and NDVI (7, 7, and 0.76, respectively) was observed in response to PC at 460 g ai ha⁻¹ 40 DAIT. Decreasing the rate of PC to 235 g ai ha⁻¹ and adding TE at 96 g ai ha⁻¹ produced similar TC, TQ, and NDVI (6.8, 7, and 0.74, respectively) as PC at 460 g ai ha⁻¹.

At 26 DAIT, the greatest % GI was observed in response to PC (34%–44%) and TE + PC (29%), while TE exhibited the lowest % GI (10%–15%) (Table 4). At 56 DAIT, PC at 460 g ai ha⁻¹ resulted in the greatest % GI (42%) followed by (fb) TE + PC (30%). All other treatments resulted in % GI of 22%–26%.

TABLE 3 Turfgrass color, turfgrass quality, and normalized difference vegetation index (NDVI) of JSC 2-21-18 hybrid bermudagrass in response to plant growth regulator treatments applied in Athens, GA.

Treatment ^a	Rate (g ai ha ⁻¹)	40 DAIT		
		Turfgrass color ^b	Turfgrass quality	NDVI
Non-treated check	N/A	6.0c	6.5c	0.64c
TE	96	6.6b	6.6bc	0.71b
TE	126	6.5b	6.9ab	0.71b
PC	235	6.6b	6.9ab	0.73ab
PC	460	7.0a	7.0a	0.76a
TE + PC	96 + 235	6.8ab	7.0a	0.74ab
LSD (0.05)	N/A	0.3	0.3	0.04

Note: Means within a column followed by the same lowercase letter are not significantly different according to Fisher's protected LSD test at $\alpha = 0.05$.

Abbreviations: DAIT, days after initial treatment; LSD, least significant difference; N/A, not applicable; PC, prohexadione calcium; TE, trinexapac-ethyl.

^aPlant growth regulators were applied with a CO₂-powered backpack sprayer equipped with XR8003VS nozzles calibrated to deliver 375 L ha⁻¹ at 221 kPa.

^bVisual ratings of turfgrass color and turfgrass quality were recorded on a scale of 1–9 with a rating of 6 considered acceptable. NDVI was measured with a Field Scout CM 1000. An average of three measurements was taken to represent each plot at each rating date.

TABLE 4 Growth inhibition (%) of JSC 2-21-18 hybrid bermudagrass in response to plant growth regulator treatments applied in Athens, GA.

Treatment ^a	Rate (g ai ha ⁻¹)	Growth inhibition (%)		
		26 DAIT	56 DAIT	84 DAIT
TE	96	10c	22b	31b
TE	126	15c	25b	32b
PC	235	34ab	26b	41ab
PC	460	44a	42a	41ab
TE + PC	96 + 235	29b	30ab	46a
LSD (0.05)	N/A	10	12	10

Note: Growth inhibition (%) was calculated by comparing clippings within treated plots to the non-treated check within the same replication. Means within a column followed by the same lowercase letter are not significantly different according to Fisher's protected LSD test at $\alpha = 0.05$.

Abbreviations: DAIT, days after initial treatment; N/A, not applicable; LSD, least significant difference; PC, prohexadione calcium; TE, trinexapac-ethyl.

^aPlant growth regulators were applied with a CO₂-powered backpack sprayer equipped with XR8003VS nozzles calibrated to deliver 375 L ha⁻¹ at 221 kPa.

At 84 DAIT, TE + PC resulted in the greatest % GI (46%) fb PC (41%), regardless of rate, while TE only resulted in % GI of 31%–32%. Similarly, de Marchi et al. (2014) reported a 41% reduction in Tifway hybrid bermudagrass height in response to sequential applications of PC at 200 g ai ha⁻¹, but a greater reduction (38%) following sequential applications of TE at 113 g ai ha⁻¹. Fagerness and Yelverton (2000) also reported greater regulation ($\leq 40\%$) of Tifway hybrid bermudagrass in response to sequential applications of TE at 71–107 g ai ha⁻¹. Finally, Reasor et al. (2018) observed slightly greater peak regulation of ultradwarf hybrid bermudagrass cultivars TifEagle (51%), P18 (50%), and Champion Dwarf (PP9888) (54%) following PC at 154 g ai ha⁻¹, while TE at 34 g ai ha⁻¹ resulted in greater but more variable peak regulation (TifEagle, 49%; P18, 62%; Champion Dwarf (PP9888), 56%). Mowing height differences between conducted trials may account for some of the discrepancies in regulation, regardless of active ingredient or application rate.

Several postemergence herbicides were safely applied to JSC 2-21-18 hybrid bermudagrass. Although topamezone

+ metribuzin, quinclorac, foramsulfuron, and sulfosulfuron resulted in reductions in either TC, TQ, or NDVI 3 WAT, injury was transient and no longer detected a week later. Prolonged phytotoxicity was only observed in response to 2,4-D + triclopyr + dicamba + pyraflufen and may be associated with the environmental conditions present at application. Temperatures exceeded 33°C at application and the 2,4-D + triclopyr + dicamba + pyraflufen (4-Speed XT[®]) label clearly states “when air temperatures exceeds 90 F, temporary turf injury may result from broadcast applications” (Anonymous, 2015b).

Greater TC, TQ, and NDVI of JSC 2-21-18 hybrid bermudagrass were observed in response to PC than TE. GI was also greater in response to PC than TE. Previous research by Beam and Askew (2005) reported that annual bluegrass (*Poa annua* L.) and Kentucky bluegrass (*P. pratensis* L.) were regulated by PC at lower rates than perennial ryegrass (*Lolium perenne* L.). Laboratory experiments using ¹⁴C-PC revealed that annual and Kentucky bluegrass absorbed and translocated more PC to roots than perennial ryegrass

(Beam & Askew, 2007). These differences may explain the differential rate responses observed in field experiments by Beam and Askew (2005), as well as the increased regulation of JSC 2-21-18 hybrid bermudagrass with PC compared to TE. Further research may be warranted to evaluate the response of JSC 2-21-18 hybrid bermudagrass to herbicides and plant growth regulators in other environments and climates.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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