

ORIGINAL ARTICLE

Applied Turfgrass Science

Shoulder season plant growth regulator programs for *Poa annua* control in creeping bentgrass putting greens in Tennessee

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Assigned to Associate Editor Matthew Elmore.

Abstract

Many golf course superintendents rely on plant growth regulators (PGRs) as a primary means of managing *Poa annua* L. in creeping bentgrass (*Agrostis stolonifera* L.), particularly the early-stage gibberellic acid inhibitor paclobutrazol (Trimmit 2SC; Syngenta Professional Products). While herbicides for *Poa annua* control are often applied during fall and winter, there is limited information regarding the efficacy of shoulder season PGR applications for *Poa annua* control. Trials were conducted in Knoxville, TN, during 2023 and 2024, to evaluate the efficacy of prohexadione-calcium (Anew EZ; Cleary Chemicals) at 18 fl oz ac⁻¹, prohexadione-calcium + paclobutrazol at 18 fl oz ac⁻¹ + 5 fl oz ac⁻¹, trinexapac-ethyl (Primo Maxx; Syngenta Professional Products) at 6 fl oz ac⁻¹, trinexapac-ethyl + paclobutrazol at 6 fl oz ac⁻¹ + 5 fl oz ac⁻¹, and paclobutrazol at 5 fl oz ac⁻¹. A non-treated check was included for comparison along with the selective herbicide methiozolin (PoaCure; Moghu USA) at 0.2 gal ac⁻¹. PGR treatments were applied at ~14-day intervals during October and November and at ~28-day intervals thereafter. Methiozolin was applied twice in the fall of each year. Prohexadione-calcium + paclobutrazol, trinexapac-ethyl + paclobutrazol, and paclobutrazol alone controlled *Poa annua* 75%–88% by 22 weeks after initial treatment (WAIT) in 2023 and 93%–94% by 22 WAIT in 2024. Combinations of prohexadione-calcium or trinexapac-ethyl with paclobutrazol led to a reduction in *Poa annua* coverage of ≥80% compared with non-treated check plots at 22 WAIT in 2024. Transient creeping bentgrass injury was observed yearly with paclobutrazol-containing treatments and was likely related to overregulation from applying treatments when ≤196 growing degree days had accumulated.

Abbreviations: GDD_{0C}, growing degree days; PGR, plant growth regulator; WAIT, weeks after initial treatment.

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Plain Language Summary

Creeping bentgrass putting greens on golf courses are often infested with *Poa annua* L., a troublesome grassy weed. This study evaluated the efficacy of shoulder season applications of plant growth regulators for *Poa annua* control. Replicated field trials were conducted in 2023 and 2024 in Knoxville, TN. Overall, prohexadione-calcium + paclobutrazol, trinexapac-ethyl + paclobutrazol, and paclobutrazol alone effectively controlled *Poa annua* in treated plots.

1 | INTRODUCTION

Poa annua L. is a problematic weed of all turfgrass systems (McCurdy et al., 2025), particularly creeping bentgrass (*Agrostis stolonifera* L.) putting greens, where few selective herbicides are labeled for control (Ervin et al., 2017). Methiozolin (PoaCure; Moghu USA) became the only selective herbicide labeled for postemergence *Poa annua* control in creeping bentgrass putting greens in 2019 (Kenny, 2019). Methiozolin efficacy for *Poa annua* control in creeping bentgrass putting greens is well documented (Brosnan et al., 2013; Askew & McNulty, 2014; Xiong et al., 2015). Due to the cost (\$528) associated with treatment at the label rate of 0.2 gal ac⁻¹ and the requirement for multiple applications to achieve effective postemergence *Poa annua* control (Anonymous, 2025a), many golf courses lack the financial resources to use methiozolin.

Limited selective herbicide options for managing *Poa annua* in creeping bentgrass have led golf course superintendents to rely heavily on plant growth regulators (PGRs), particularly the early-stage gibberellic acid inhibitor paclobutrazol (e.g., Trimmit 2 SC; Syngenta Professional Products). Sequential applications of paclobutrazol have been shown to effectively suppress *Poa annua* in creeping bentgrass fairways (Diehl et al., 2022; McCullough et al., 2005). However, the efficacy of these sequential application programs can vary by geographic location (Reicher et al., 2015). A 3-year study across several Midwest locations reported reductions in *Poa annua* cover in creeping bentgrass putting greens following six applications of paclobutrazol (spaced 28 days apart) at 16 fl oz ac⁻¹ from April to September; this response was similar to that achieved with four applications of PoaCure at 25.6 fl oz ac⁻¹ (Patton et al., 2019). At the end of a 2-year study in California, 15 paclobutrazol applications (spaced 14 days apart from May to November) at 3.84, 5.25, or 7.6 fl oz ac⁻¹ significantly reduced *P. annua* cover in a 'Pure Distinction' creeping bentgrass putting green compared to non-treated check plots (Petelewicz et al., 2021).

Prohexadione-calcium (e.g., Anew; Cleary Chemicals) is a late-stage gibberellic acid inhibitor used to regulate the growth of creeping bentgrass (Husiny et al., 2023). In addition to reducing clipping yield, winter applications of

prohexadione-calcium suppress *Poa annua* seedhead production in spring (Peppers et al., 2021). There has been minimal work evaluating prohexadione-calcium as part of a PGR program aimed at *Poa annua* eradication from creeping bentgrass.

Herbicide programs for *Poa annua* control frequently involve applications of pre- and/or postemergence herbicides in the fall (Brosnan et al., 2020). However, information regarding the efficacy of PGR applications during shoulder seasons (i.e., fall, winter, and spring) for *Poa annua* management is limited. While enhanced *Poa annua* seedhead suppression with winter applications of mefluidide and ethephon has been reported in the Southeast Region (Askew, 2017), little is known regarding the efficacy of shoulder season applications of paclobutrazol or prohexadione-calcium for *Poa annua* control in creeping bentgrass putting greens. Considering that prohexadione-calcium reduces freeze tolerance of *Poa annua* in winter (DaCosta et al., 2022), it could be useful as part of a shoulder season PGR program aimed at *Poa annua* eradication. We hypothesized that shoulder season applications of paclobutrazol and prohexadione-calcium could control *Poa annua* in a creeping bentgrass putting green, similar to PoaCure. We conducted a replicated experiment with the objective of exploring this hypothesis in detail.

2 | MATERIALS AND METHODS

A replicated field experiment was conducted on a creeping bentgrass ('Penncross') chipping green at Three Ridges Golf Course (Knoxville, TN; 36.0522°N, 83.5049°W) naturally infested with *Poa annua*. Prior to initiating research, *Poa annua* cover within this green measured 53%. Putting greens at this golf course were constructed according to United States Golf Association construction specifications (USGA, 2018) and contained significant quantities of organic material. Kahiu et al. (2024) sampled this location. They reported 7.4% total organic material (e.g., soil organic matter plus roots, rhizomes, stolons, thatch, mat, verdure) in the uppermost 0.78 inches (2 cm) of the rootzone, as well as soil organic matter content (with aboveground plant material removed) of 3%

TABLE 1 Application dates for plant growth regulator treatments (prohexadione-calcium [Anuew EZ^a], paclobutrazol [Trimmit 2SC^b], and trinexapac-ethyl [Primo Maxx^b] alone or in combination with one another) to manage *Poa annua* in a creeping bentgrass chipping green in Knoxville, TN.

Year	Application dates ^c						
1 (2023–2024)	Oct. 2	Oct. 16	Oct. 30	Nov. 13	Dec. 13	Jan. 11	Feb. 5
2 (2024–2025)	Oct. 2	Oct. 14	Oct. 28	Nov. 12	Dec. 11	— ^d	Jan. 28

^aCleary Chemicals.

^bSyngenta Professional Products.

^cPlant growth regulators were applied on all of the dates listed. The selective herbicide methiozolin (PoaCure; Moghu USA) was applied on October 2 and November 13, 2023, as well as on October 2 and November 12, 2024.

^dApplications were not made since the daily average air temperature was <32°F from January 7 to January 16, 2025.

throughout a 3.9-inch (10 cm) core. Soil pH measured 5.8 with concentrations of P, K, S, and Ca exceeding minimum levels of sustainable nutrition guidelines (Woods et al., 2016).

The experiment was designed as a randomized complete block with four replications of plots measuring 5 × 6 ft. Separate plots were used each year; the eastern side of the green was used for the 2023 experiment, whereas the western side was used in 2024. The green was mowed daily at 0.125 inches with a triplex reel mower (Greensmaster 3150-Q; Toro Company). No fungicides were applied to the trial site (during the data collection period) in the first year of the experiment. During the data collection period in 2024, this site was treated with chlorothalonil (ProtectMAX Chlorothalonil 6L; Harrell's Company) at 5 fl oz ac⁻¹ and fluoxastrobin (Fame SC; Envu Environmental Science) at 16 fl oz ac⁻¹. Additionally, the site was treated with azoxystrobin + propiconazole (Headway G; Syngenta Professional Products) at 5 lb per 1000 ft² in January 2025. No PGRs were applied to the trial site during this study in either year. Nutrients were applied via applications of EarthMax Organic Soil + Foliar Additive, N30 Plus, Cal Plus, 18-3-6 with Ummax, and BioMax 4-0-0 (all from Harrell's Company). All fertilizer applications were applied according to label directions.

Plant growth regulator treatments in this study included prohexadione-calcium (Anuew EZ) at 18 fl oz ac⁻¹, prohexadione-calcium + paclobutrazol (Trimmit 2SC) at 18 fl oz ac⁻¹ + 5 fl oz ac⁻¹, trinexapac-ethyl (Primo Maxx; Syngenta Professional Products) at 6 fl oz ac⁻¹, trinexapac-ethyl + paclobutrazol at 6 fl oz ac⁻¹ + 5 fl oz ac⁻¹, as well as paclobutrazol at 5 fl oz ac⁻¹. Non-treated check plots were included in each replication for comparison. Prohexadione-calcium and trinexapac-ethyl application rates in this study align with current label directions for use on creeping bentgrass putting greens (Anonymous, 2015, 2025b). Our paclobutrazol rate was lower than the 7.6 fl oz ac⁻¹ rate reported to cause the highest degree of creeping bentgrass injury on Pure Distinction creeping bentgrass when applied at 14-day intervals from May to November (Petelewicz et al., 2021). The selective herbicide methiozolin was also applied at the label rate of 0.2 gal ac⁻¹ for comparison (Anonymous,

2025a). All treatments were applied using a CO₂-pressurized sprayer at 40 gal ac⁻¹ with flat-fan nozzle tips (XR8002; TeeJet Technologies). In-ground irrigation at the site was used to irrigate treatments into the soil within 14 hours after application. Plant growth regulator treatments were applied at ~14-day intervals during October and November and at ~28-day intervals thereafter (Table 1). Methiozolin was applied twice in the fall of each year: on October 2 and November 13, 2023, and on October 2 and November 12, 2024. Treatments were initiated when the 24-hour average air temperature fell below 66°F, as this threshold has been associated with favorable conditions for *Poa annua* emergence (Taylor et al., 2021).

Poa annua control was visually assessed at 2, 4, 6, 10, 14, and 22 weeks after initial treatment (WAIT) each year using a 0% (i.e., no control) to 100% (i.e., complete kill) scale relative to non-treated check plots in each replication. Creeping bentgrass injury was visually assessed on the same dates using a similar percentage-based scale relative to non-treated check plots in each replication. At 22 WAIT each year, *Poa annua* cover was visually assessed as well. Use of visual ratings is common in turfgrass weed science field trials; previous studies have reported no benefits from digital image analysis or line-intersect quantification in lieu of visual assessments (Hoyle et al., 2013). All data were subjected to a combined ANOVA in R (version 4.2.2; R Core Team, 2024) using expected mean squares of McIntosh (1983) to determine whether years could be combined. When appropriate, means were separated using the *LSD.test* function found within the agricolae package (De Mendiburu & Simon, 2015). Lastly, *Poa annua* control and cover data collected at 22 WAIT were subjected to Pearson's correlation in Prism (GraphPad Prism; version 10.4.1).

3 | RESULTS AND DISCUSSION

Significant year × treatment interactions were detected in *Poa annua* control and creeping bentgrass injury data. Therefore, data from each year were analyzed separately and

TABLE 2 *Poa annua* control following applications of prohexadione-calcium (Anuew EZ), paclobutrazol (Trimmit 2SC), and trinexapac-ethyl (Primo Maxx) alone or in combination with one another. Applications were made to a creeping bentgrass (*Agrostis stolonifera* L.) chipping green in Knoxville, TN, during the fall, winter, and early spring of 2023–2024 and 2024–2025. Application dates each year are presented in Table 1.

Year	Treatment ^a	Rate (ac ⁻¹)	<i>Poa annua</i> control ^b					
			2 WAIT	4 WAIT	6 WAIT	10 WAIT	14 WAIT	22 WAIT
			%					
2023	Anuew EZ ^c	18 fl oz	8	49	28	35	40	25
	Anuew EZ + Trimmit ^d	18 fl oz + 5 fl oz	13	75	83	74	88	88
	Primo Maxx ^d	6 fl oz	1	0	0	20	0	0
	Primo Maxx + Trimmit	6 fl oz + 5 fl oz	6	73	65	68	84	85
	Trimmit	5 fl oz	4	68	58	53	78	75
	PoaCure ^e	0.2 gal	5	55	43	25	53	64
LSD _{0.05}			3	9	15	29	6	13
2024	Anuew EZ	18 fl oz	4	58	50	49	10	33
	Anuew EZ + Trimmit	18 fl oz + 5 fl oz	31	90	93	93	95	94
	Primo Maxx	6 fl oz	0	0	0	0	0	0
	Primo Maxx + Trimmit	6 fl oz + 5 fl oz	19	88	85	86	71	94
	Trimmit	5 fl oz	23	85	85	86	94	93
	PoaCure	0.2 gal	0	10	0	8	83	95
LSD _{0.05}			6	9	7	9	26	8

Abbreviations: LSD, Fisher's protected LSD test at $\alpha = 0.05$; WAIT, weeks after initial treatment.

^aPlant growth regulators were applied at ~14-day intervals during October and November each year. Intervals were adjusted to 28 days thereafter. Application dates for all plant growth regulator treatments are presented in Table 1. The selective herbicide methiozolin (PoaCure) was applied on October 2 and November 13, 2023, as well as on October 2 and November 12, 2024.

^b*Poa annua* control rated relative to non-treated check plots in each replication using a 0% (i.e., no control) to 100% (i.e., complete kill) scale.

^cCleary Chemicals.

^dSyngenta Professional Products.

^eMoghu USA.

are presented in Tables 2–4. There was a marked increase in *Poa annua* control observed by 4 WAIT each year (Table 2). Applications of prohexadione-calcium + paclobutrazol, trinexapac-ethyl + paclobutrazol, and paclobutrazol alone resulted in 68%–75% control by 4 WAIT in 2023 and 85%–90% control in 2024 (Table 2). Mixtures containing paclobutrazol resulted in greater *Poa annua* control than prohexadione-calcium or trinexapac-ethyl applied alone. This relationship was consistent throughout the duration of the trial each year with prohexadione-calcium + paclobutrazol, trinexapac-ethyl + paclobutrazol, and paclobutrazol alone ranking in the top statistical grouping for *Poa annua* control from 4 to 22 WAIT. By the end of the study, these applications controlled *Poa annua* 75%–88% in 2023 and 93%–94% in 2024 (Table 2). *Poa annua* control with paclobutrazol-containing mixtures in the present study aligns with previous reports of efficacy following 15 in-season (May–November) applications of flurprimidol + paclobutrazol + trinexapac-ethyl in California (Petelewicz et al., 2021). Trinexapac-ethyl efficacy in the present study was poor in both years, similar to previously reported results (Reicher et al., 2015).

Assessments of *Poa annua* cover at 22 WAIT were significantly correlated ($r = -0.904$, $P \leq 0.0001$) with

visual assessments of *Poa annua* control made on the same date. *Poa annua* cover in plots treated with prohexadione-calcium + paclobutrazol, trinexapac-ethyl + paclobutrazol, or paclobutrazol alone measured $\leq 18\%$ by 22 WAIT in 2023 and 6% by 22 WAIT in 2024 (Table 3). Comparatively, *Poa annua* cover in non-treated check plots measured 39%–44% on the same dates. Reductions in *Poa annua* cover with shoulder season applications of prohexadione-calcium + paclobutrazol, trinexapac-ethyl + paclobutrazol, or paclobutrazol in the present study were greater than those reported with in-season applications of paclobutrazol on creeping bentgrass putting greens in the Midwest (Patton et al., 2019). Reductions in *Poa annua* cover with paclobutrazol in this study align with those reported by Petelewicz et al. (2021) following paclobutrazol applications (7.6 fl oz ac⁻¹) at 14-day intervals, from May to November, for two consecutive seasons. Treatment with the aforementioned PGRs reduced *Poa annua* cover to a greater degree than methiozolin by 22 WAIT in 2023; however, reductions in *Poa annua* cover with applications of prohexadione-calcium + paclobutrazol, trinexapac-ethyl + paclobutrazol, or paclobutrazol alone were similar to reductions seen with methiozolin in 2024.

TABLE 3 *Poa annua* cover (22 weeks after initial treatment) following applications of prohexadione-calcium (Anuew EZ), paclobutrazol (Trimmit 2SC), and trinexapac-ethyl (Primo Maxx) alone or in combination with one another. Applications were made to a creeping bentgrass (*Agrostis stolonifera* L.) chipping green in Knoxville, TN, during the fall, winter, and early spring of 2023–2024 and 2024–2025. Application dates each year are presented in Table 1.

Treatment ^a	Rate (ac ⁻¹)	<i>Poa annua</i> cover	
		2023	2024
		%	
Non-treated check	—	44	39
Anuew EZ ^b	18 fl oz	45	28
Anuew EZ + Trimmit ^c	18 fl oz + 5 fl oz	6	6
Primo Maxx ^c	6 fl oz	46	39
Primo Maxx + Trimmit	6 fl oz + 5 fl oz	9	6
Trimmit	5 fl oz	18	6
PoaCure ^d	0.2 gal	31	5
LSD _{0.05}		14	9

Abbreviations: LSD, Fisher's protected LSD test at $\alpha = 0.05$.

^aPlant growth regulators were applied at 14-day intervals during October and November each year. Intervals were adjusted to 28 days thereafter. Application dates for all treatments are presented in Table 1. The selective herbicide methiozolin (PoaCure) was applied on October 2 and November 13, 2023, as well as on October 2 and November 12, 2024.

^bCleary Chemicals.

^cSyngenta Professional Products.

^dMoghu USA.

TABLE 4 Creeping bentgrass (*Agrostis stolonifera* L.; 'Penncross') injury following applications of prohexadione-calcium (Anuew EZ), paclobutrazol (Trimmit 2SC), and trinexapac-ethyl (Primo Maxx) alone or in combination with one another. Applications were made to a creeping bentgrass chipping green in Knoxville, TN, during the fall, winter, and early spring of 2023–2024 and 2024–2025. Application dates each year are presented in Table 1.

Year	Treatment ^a	Rate (ac ⁻¹)	Creeping bentgrass injury ^b					
			2 WAIT	4 WAIT	6 WAIT	10 WAIT	14 WAIT	22 WAIT
			%					
2023	Anuew EZ ^c	18 fl oz	10	25	3	1	0	0
	Anuew EZ + Trimmit ^d	18 fl oz + 5 fl oz	14	41	20	14	0	0
	Primo Maxx ^d	6 fl oz	0	5	0	0	0	0
	Primo Maxx + Trimmit	6 fl oz + 5 fl oz	8	35	5	5	0	0
	Trimmit	5 fl oz	5	30	4	3	0	0
	PoaCure ^e	0.2 gal	3	0	0	0	0	0
LSD _{0.05}			4	6	5	6	—	—
2024	Anuew EZ	18 fl oz	3	8	3	0	0	0
	Anuew EZ + Trimmit	18 fl oz + 5 fl oz	16	38	31	0	13	0
	Primo Maxx	6 fl oz	0	0	0	0	0	0
	Primo Maxx + Trimmit	6 fl oz + 5 fl oz	1	35	15	0	1	0
	Trimmit	5 fl oz	0	13	4	0	3	0
	PoaCure	0.2 gal	0	0	0	0	23	0
LSD _{0.05}			8	4	8	—	11	—

Abbreviations: LSD, Fisher's protected LSD test at $\alpha = 0.05$; WAIT, weeks after initial treatment.

^aPlant growth regulators were applied at 14-day intervals during October and November each year. Intervals were adjusted to 28 days thereafter. Application dates for all treatments are presented in Table 1. The selective herbicide methiozolin (PoaCure) was applied on October 2 and November 13, 2023, as well as October 2 and November 12, 2024.

^bCreeping bentgrass injury was rated relative to non-treated check plots in each replication using a 0% (i.e., no injury) to 100% (i.e., complete phytotoxicity) scale.

^cCleary Chemicals.

^dSyngenta Professional Products.

^eMoghu USA.

All PGR treatments, including paclobutrazol, resulted in significant creeping bentgrass injury by 4 WAIT each year (Table 4). For example, treatment with prohexadione-calcium + paclobutrazol, trinexapac-ethyl + paclobutrazol, and paclobutrazol alone resulted in 30%–41% creeping bentgrass injury by 4 WAIT in 2023 and 13%–38% injury by 4 WAIT in 2024. This foliar injury may be the result of overregulation caused by applying these PGRs at ~14-day intervals. When used to regulate creeping bentgrass clipping yield, the optimal reapplication interval for paclobutrazol is 269–302 growing degree days (GDD_{0C}) using a base temperature of 0 °C (Kreuser et al., 2018). In this study, where paclobutrazol applications were made with the intention of *Poa annua* control, only 196 and 183 GDD_{0C} accumulated between the initial application and sequential treatment in 2023 and 2024, respectively. This could have led to overregulation that manifested in foliar injury (Whitlark, 2019). Creeping bentgrass injury, associated with reductions in growth rate, has been reported following in-season applications of paclobutrazol (7.6 fl oz ac⁻¹) applied at 14-day intervals (Petelewicz et al., 2021). Creeping bentgrass in the present study recovered each year by 10 WAIT, with injury ranging from 0% to 14% and no injury reported thereafter. Shoulder season growing conditions in Tennessee may have aided recovery, as the potential for cool-season turfgrass growth exceeded 75% for 41 of the first 90 days of the study in 2023 and 49 of the first 90 days in 2024.

4 | CONCLUSIONS

Overall, our results indicate that shoulder season applications of prohexadione-calcium + paclobutrazol, trinexapac-ethyl + paclobutrazol, or paclobutrazol alone can effectively manage *Poa annua* in creeping bentgrass putting greens in Tennessee. This information will be useful to golf course superintendents who cannot afford to control *Poa annua* with the selective herbicide methiozolin. However, creeping bentgrass injury observed during the first 4 weeks after application will reduce turfgrass quality and may not be tolerable to some practitioners. Similarly, creeping bentgrass injury observed after applying these PGRs at short intervals may not be applicable to other regions of the United States where growth potential in the fall does not provide sufficient time for creeping bentgrass to recover from injury associated with overregulation following treatment. Future research comparing shoulder season applications of paclobutrazol to flurprimidol and mixtures of flurprimidol + paclobutrazol + trinexapac-ethyl is warranted. Reductions in *Poa annua* cover and enhancements in creeping bentgrass color have been reported following applications of flurprimidol and flurprimidol + paclobutrazol + trinexapac-ethyl from May through November (Petelewicz et al., 2021) in southern California.

AUTHOR CONTRIBUTIONS

James T. Brosnan: Formal analysis; funding acquisition; investigation; project administration; resources; supervision; writing—original draft; writing—review & editing. **Gregory K. Breeden:** Data curation; methodology; writing—review & editing. **Aaron Hathaway:** Resources; writing—review & editing.

ACKNOWLEDGMENTS

The authors acknowledge and thank Nufarm Americas for their financial support of this project in 2023. We thank the Knox County Department of Parks and Recreation, specifically Chris Hurley, superintendent, at Three Ridges Golf Course.

CONFLICT OF INTEREST STATEMENT

Aaron Hathaway is an employee of Nufarm Americas, who provided funding to support the first year of this study.

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How to cite this article: Brosnan, J. T., Breeden, G. K., & Hathaway, A. (2025). Shoulder season plant growth regulator programs for *Poa annua* control in creeping bentgrass putting greens in Tennessee. *Crop, Forage & Turfgrass Management*, 11, e70091. <https://doi.org/10.1002/cft2.70091>