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Turfgrass Science

Growing degree-days optimize trinexapac-ethyl reapplications on ultradwarf bermudagrass putting greens: II. Testing a reapplication schedule

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Abstract

Trinexapac-ethyl (TE) is commonly applied to ultradwarf bermudagrass [*Cynodon dactylon* (L.) Pers. × *C. transvaalensis* Burtt-Davy] putting greens for growth suppression and secondary benefits. Improperly timed reapplications will reduce the benefits of TE, but knowing when to reapply is difficult because suppression duration is affected by environmental conditions, especially temperature. In another experiment we determined that GDD with a base temperature of 0 ˚C (GDD_0) was the most precise unit for predicting the maximum suppression point (MSP) after a TE application on a 'MiniVerde' ultradwarf bermudagrass putting green. The model suggested that the MSP occurred at 262 GDD_0 after the TE application. The objective of this second experiment was to test GDD_0 reapplication intervals for an extended period of time. We included four GDD_0 intervals (100, 200, 400, and 600) and two TE rates (0.022 and 0.044 kg a.i. ha^{-1}). We hypothesized that reapplying TE before the MSP would result in a consistent suppression magnitude from day to day (i.e., consistent daily growth), which should be an ideal growth pattern for turfgrass managers. The 100- and 200-GDD_0 intervals yielded consistent suppression magnitude throughout the experiment, and suppression magnitude increased with the higher TE rate. In contrast, the 400- and 600-GDD_0 intervals allowed fluctuation in suppression magnitude from day to day. Discoloration occurred after initial applications and was more severe for the higher TE rate.

1 | INTRODUCTION

Turfgrass managers apply trinexapac-ethyl (TE) to ultradwarf bermudagrass [*Cynodon dactylon* (L.) Pers. × *C. transvaalensis* Burtt-Davy] putting greens primarily to maintain consistent ball roll and improve quality (Baldwin, Liu, McCarty, Luo, & Toler, 2009; Fagerness, Yelverton, Isgrigg, & Cooper, 2000; King, Blundell, Evans, Mander, & Wood, 1997; Kreuser & Soldat, 2012; McCarty, Willis, Toler, & Whitwell, 2011; McCullough, Liu, & McCarty, 2005a). These enhancements are possible because TE suppresses vertical turfgrass growth, but failure to maintain suppression with reapplications of TE may result in a loss of these benefits. Properly timing a reapplication is difficult because

Abbreviations: DAIT, days after initial treatment; GA, gibberellic acid; GDD_0, growing degree-days with a base temperature of 0 ˚C; GDD_{10}, growing degree-days with a base temperature of 10 ˚C; MSP, maximum suppression point; TE, trinexapac-ethyl.

suppression duration varies with environmental conditions, such as temperature (Kreuser & Soldat, 2011).

Recent research suggested that this reapplication problem can be resolved by using a growing degree-day (GDD) reapplication schedule. A 200-GDD with a base temperature of 0 ˚C (GDD_0) TE reapplication interval ensures the suppression phase is maintained on creeping bentgrass (*Agrostis stolonifera* L.) putting greens throughout the growing season (Kreuser & Soldat, 2011). As for ultradwarf bermudagrass putting greens, Reasor et al. (2018) recommended that TE be reapplied to 'MiniVerde,' 'Champion,' and 'TifEagle' every 230, 216, and 216 GDD with a base temperature of 10 ˚C (GDD_{10}), respectively. This interval was calculated by multiplying the total GDD_{10} accumulation at the maximum suppression point (MSP) by 1.3 (the *1.3 × method*), which was an effective method for maintaining the suppression phase of creeping bentgrass (Kreuser & Soldat, 2011; Kreuser, Obear, Michael, & Soldat, 2018). Additionally, in another experiment on a MiniVerde ultradwarf bermudagrass putting green, we determined that GDD_0 predicted the MSP after a TE application more precisely than calendar days and GDD_{10} (Brown et al., 2021). The GDD_0 model indicated that the MSP occurred at 262 GDD_0 after a TE (0.044 kg a.i. ha^{-1}) application.

The objective of this experiment was to test GDD_0 reapplication schedules on a MiniVerde putting green over an extended period of time. Importantly, we posited that reapplying before the MSP is preferable to the 1.3 × method, assuming turfgrass managers prefer consistent daily growth rates. Reapplying shortly before the MSP should minimize fluctuation of the bioactive gibberellic acid (GA_1) concentration within the plant and should maintain a consistent turfgrass growth rate from day to day. In contrast, reapplying after the MSP, as with the 1.3 × method, will likely permit fluctuations in GA_1 concentration and will not maintain a consistent growth rate from day to day.

To test this theory we included four GDD_0 intervals (100, 200, 400, and 600) and two TE rates (0.022 and 0.044 kg a.i. ha^{-1}). Because the 100- and 200-GDD_0 intervals would occur before the MSP, we hypothesized that they would maintain a consistent suppression magnitude (i.e., consistent daily growth rates) throughout the experiment and enhance turfgrass quality. In contrast, because the 400- and 600-GDD_0 intervals would occur after the MSP, we hypothesized that they would result in fluctuating suppression magnitude.

Core Ideas

- Reapplying trinexapac-ethyl (TE) before the MSP will maintain consistent turfgrass growth and enhance quality.
- A 200-GDD_0 reapplication interval maintains suppression all season regardless of temperature.
- A 400-GDD_0 reapplication interval results in fluctuating suppression magnitude and daily growth.
- The lower TE rate caused less injury and still maintained suppression when reapplied before the MSP.
- Proper TE reapplications can significantly improve quality of ultradwarf bermuda putting greens.

2 | MATERIALS AND METHODS

A field experiment was conducted on a MiniVerde bermudagrass putting green at the Sports Surface Field Laboratory in Auburn, AL during 2016 and repeated in 2017. Importantly, in 2017 the experiment took place on a different section of the same MiniVerde putting green. The putting green was constructed in 1994 according to United States Golf Association specifications (USGA, 1993) and sprigged with MiniVerde in April 2004. On 1 Apr. 2016, 9 Sept. 2016, and 2 Mar. 2017, the green was hollow-tine aerated and topdressed. During the experiment the turfgrass was not topdressed or cultivated. Following green-up in April, turfgrass was fertilized with liquid urea at 12.2 kg N ha^{-1} wk^{-1}. Phosphorus and potassium were added based on soil test results. Preventative fungicides to control mini-ring (*Rhizoctonia zeae*) and dollar spot (*Sclerotinia homoeocarpa*) were applied beginning in May. This included azoxystrobin, chlorothalonil, and mancozeb, which are not known to regulate plant growth. Turfgrass was irrigated daily at approximately 80% of the estimated potential evapotranspiration.

Treatments included a standard low and high TE rate (0.022 and 0.044 kg a.i. ha^{-1}) and four GDD_0 reapplication intervals (100, 200, 400, and 600). These application intervals began on the first week of May and ended at the beginning of August (2 May to 8 Aug. 2016; 1 May to 7 Aug. 2017). Applications were made with a CO_2 sprayer calibrated to deliver 375 L ha^{-1}. Irrigation was withheld for at least 1 h following TE applications. Treatments were arranged in a randomized complete block design with four replicates on 1.5 × 1.5 m plots, and a nontreated control was included in each replication.

2.1 | Environmental conditions

A weather station (WMR300, Oregon Scientific) positioned 1.5 m above the experiment area recorded air temperature and rain. The daily high and low air temperatures were recorded in Celsius for each 24-h period beginning at midnight. Daily GDD was calculated with the equation:

$$\text{Daily GDD} = \frac{T_{\text{high}} + T_{\text{low}}}{2} - T_{\text{base}}$$

where if $[(T_{high} + T_{low})/2] < T_{base}$, then the GDD for that day is set to 0, which prevents negative GDD accumulation (McMaster & Wilhelm, 1997). Daily GDD was calculated with a 0 ˚C base temperature (Brown et al., 2021). Total GDD accumulation is the sum of daily GDD_0 beginning on the application date. Sequential applications for each interval were made on the day after the GDD_0 threshold (i.e., 100, 200, 400, or 600) was crossed.

2.2 | Data collection and analysis

Clipping yield suppression was approximated by collecting clippings 3 d per wk at 1100 ± 1 h with a Jacobsen walking greens mower (Greens King 522, Jacobsen) set at 3.4 mm. Clippings were collected as described in Brown et al. (2021). Clipping collections began 2 d after the first application and ended 25 d after the final application. Clippings were not collected on 21 June 2017 due to a tropical storm. Relative clipping yield (g g^{-1}) was calculated by dividing the weight of the treated by the nontreated within each replication. Daily growth (g m^{-2} d^{-1}) was calculated by dividing the weight of each plot by the number of days since the previous collection date to obtain an approximate daily growth rate.

Although not the main objective of this experiment, a GDD model for TE at 0.022 kg a.i. ha^{-1} was created using data from the 600-GDD_0 interval (low rate). A comparison of this model with the model for TE at 0.044 kg a.i. ha^{-1} from Brown et al. (2021) reveals the effect of TE rate on the MSP, suppression magnitude, and total suppression duration. To create this model, the data from the 600-GDD_0 interval (low rate) were pooled and plotted by cumulative GDD_0 after the most recent TE application, similar to the method of Kreuser and Soldat (2011). Next, these data were fit to a five-parameter, amplitude-damped sine regression (Figure 1) in SigmaPlot (version 14, Systat Software) and calculations were performed as described in Brown et al. (2021). This process was then repeated for cumulative GDD_{10}.

To properly analyze the effect of TE rate and GDD_0 interval on vertical growth, clipping collection data were separated into two periods: application and postapplication. The *application period* is representative of a season-long TE reapplication schedule. In contrast, the *postapplication period* demonstrates the effect of ending TE reapplications during the growing season. More specifically, the application period includes clipping collections beginning at the MSP that followed the initial application (18 May 2016 and 17 May 2017) through the clipping collection on which the final TE application was made (8 Aug. 2016 and 7 Aug. 2017). The postapplication period only includes the clipping collections that followed the final TE application (17 Aug. to 2 Sept. 2016; 16 Aug. to 1 Sept. 2017). After separating collection dates into the application period or postapplication period, data were

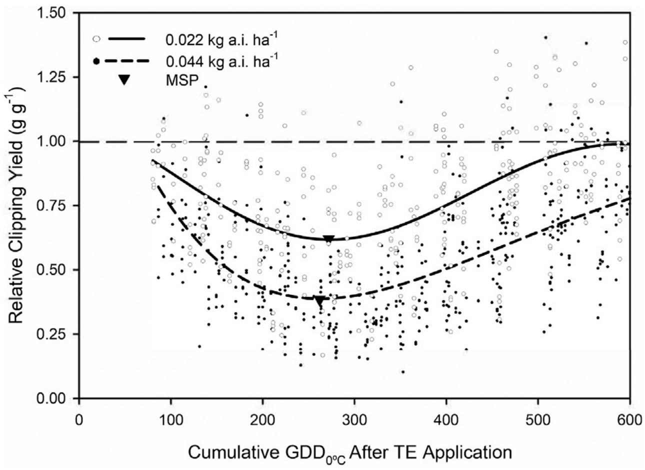

FIGURE 1 Relative clipping yield plotted by growing degree-days with a base temperature of 0 ˚C (GDD_0) after a trinexapac-ethyl (TE) application. The solid line regression—Relative yield (g g^{-1}) = $0.832 + 0.283 \times e^{\frac{-GDD}{937.93}} \times \sin(2\pi\frac{GDD}{649.18}+1.97)$—includes data pooled by year and collection date from the 600-GDD_0 (0.022 kg a.i. ha^{-1}) interval. The dashed line regression is for TE at 0.044 kg a.i. ha^{-1} (Brown et al., 2021)

subjected to repeated-measures analysis with the MIXED procedure in SAS (version 9.4, SAS Institute), and means were separated with Fisher's protected LSD (α = .05) when appropriate, such as comparing treatments within a collection date.

Visual color ratings based on the National Turfgrass Evaluation Program scale were recorded weekly following the initial application (Morris & Shearman, 2000). A visual color rating of 6 was considered minimally acceptable and 9 was considered optimal turfgrass. Turfgrass color ratings were analyzed using the MIXED procedure in SAS. Means were separated with Fisher's protected LSD (α = .05).

3 | RESULTS AND DISCUSSION

The following subsections will (a) compare the GDD_0 model for TE at 0.022 kg a.i. ha^{-1} with the GDD_0 model for TE at 0.044 kg a.i. ha^{-1} from Brown et al. (2021), (b) analyze growth during the application period, and (c) analyze growth during the postapplication period. The average air temperature during the experiment was 26.4 ˚C in 2016 and 25.3 ˚C in 2017.

3.1 | GDD model rate comparison

Ability to predict the MSP following a TE application allows for more precise reapplications that will maintain the suppression phase and the associated benefits (Kreuser & Soldat, 2011; Kreuser et al., 2018; Reasor et al., 2018). For TE

TABLE 1 Average relative clipping yield over the application period

Treatment		Average relative clipping yield[a,b]	
Interval	Rate	2016	2017
100 GDD_0	0.022	0.20b	0.25b
	0.044	0.08a	0.18a
200 GDD_0	0.022	0.45c	0.59d
	0.044	0.24b	0.32c
400 GDD_0	0.022	0.72e	0.91g
	0.044	0.46c	0.57d
600 GDD_0	0.022	0.76e	0.80f
	0.044	0.54d	0.73e
Nontreated	0	1.00f	1.00h

Note. GDD_0, growing degree-days with a base temperature of 0 ˚C.
[a]This includes collection dates beginning at the maximum suppression point following the initial application through the collection date of the final trinexapac-ethyl application (18 May 2016 to 8 Aug. 2016; and 17 May 2017 to 7 Aug. 2017). [b]Column means not sharing any letter are significantly different according to Fisher's protected LSD (α = .05).

at 0.044 kg a.i. ha^{-1}, we determined that GDD_0 is the most precise predictor of the MSP for ultradwarf putting greens, though GDD_{10} is also reported for comparison to previous research (Brown et al., 2021). To create a GDD_0 and GDD_{10} model for TE at 0.022 kg a.i. ha^{-1}, we pooled data from the 600-GDD_0 interval with TE at 0.022 kg a.i. ha^{-1} across year (not significant) and collection date. Comparing these results with the higher TE rate in Brown et al. (2021) elucidates the effect of TE rate on turfgrass suppression (Figure 1).

The resulting model for TE at 0.022 kg a.i. ha^{-1} indicates that the MSP occurred at 272 GDD_0 (158 GDD_{10}). Assuming a daily accumulation of 20–30 GDD_0 (10–20 GDD_{10}), this is very similar to the 262 GDD_0 (157 GDD_{10}) determined with TE at 0.044 kg a.i. ha^{-1} (Brown et al., 2021). In contrast, suppression magnitude at the MSP was 38% for this lower rate, whereas it was 61% for 0.044 kg a.i. ha^{-1}. This reduced suppression at the MSP resulted in a shorter total suppression phase duration of only 622 GDD_0 (385 GDD_{10}), compared with 997 GDD_0 (650 GDD_{10}) for TE at 0.044 kg a.i. ha^{-1}. Additionally, the average suppression magnitude over the entire suppression phase was only 18%, whereas it was 25% for TE at 0.044 kg a.i. ha^{-1}. These comparisons suggest that TE rate does not affect duration to the MSP (at least at typical TE rates), but TE rate does affect suppression magnitude at the MSP and total suppression phase duration (Brown et al., 2021).

We conclude that, at the label rate (0.026 kg a.i. ha^{-1}), a single TE application will most likely not suppress ultradwarf bermudagrass putting greens by an average of 50% over a 28-d period, as claimed on the Primo Maxx label. The TE rate required to suppress growth to this extent would likely produce unacceptable phytotoxicity if applied in a single application. However, the following section will indicate that properly timed reapplications can maintain greater than 50% suppression and enhance turfgrass color.

3.2 | Analysis of the application period

Year was significant for both relative clipping yield (g g^{-1}) and daily growth (g m^{-2} d^{-1}), so results are presented by year (Table 1). For both years, GDD_0 interval, rate, and the GDD_0 interval × rate interaction were significant, so the four GDD_0 intervals will be discussed separately by TE rate. Such an interaction can be explained based on cumulative TE applied throughout the season. Also, collection date and collection date × GDD_0 interval (but not rate) were significant, so data are presented by collection date (Figures 2 and 3). Turfgrass color ratings were significantly different by year, rate, GDD_0 interval, and rate × GDD_0 interval, so these data are also presented separately (Table 2).

3.2.1 | 100 GDD_0

In both years, the low rate (0.022 kg a.i. ha^{-1}) and the high rate (0.044 kg a.i. ha^{-1}) had significantly less clipping yield than the nontreated on every collection date during the application period (Figure 2). The low rate had significantly more clipping yield than the high rate on nine collection dates in 2016 and only one in 2017. The average suppression for the low rate was 80% in 2016 and 75% in 2017, compared with 92% in 2016 and 82% in 2017 for the high rate (Table 1).

Although both resulted in very consistent daily growth, the high rate is unacceptable for high-quality turfgrass because it resulted in color ratings that remained significantly lower than the nontreated until 67 d after the initial treatment (DAIT) in 2016 and 53 DAIT in 2017 (Table 2). On the other hand, color of the low rate was equal to or significantly better than the nontreated by 21 DAIT in both years. In climates like Auburn, AL, 100 GDD_0 occurs every 4–5 d during the growing season;

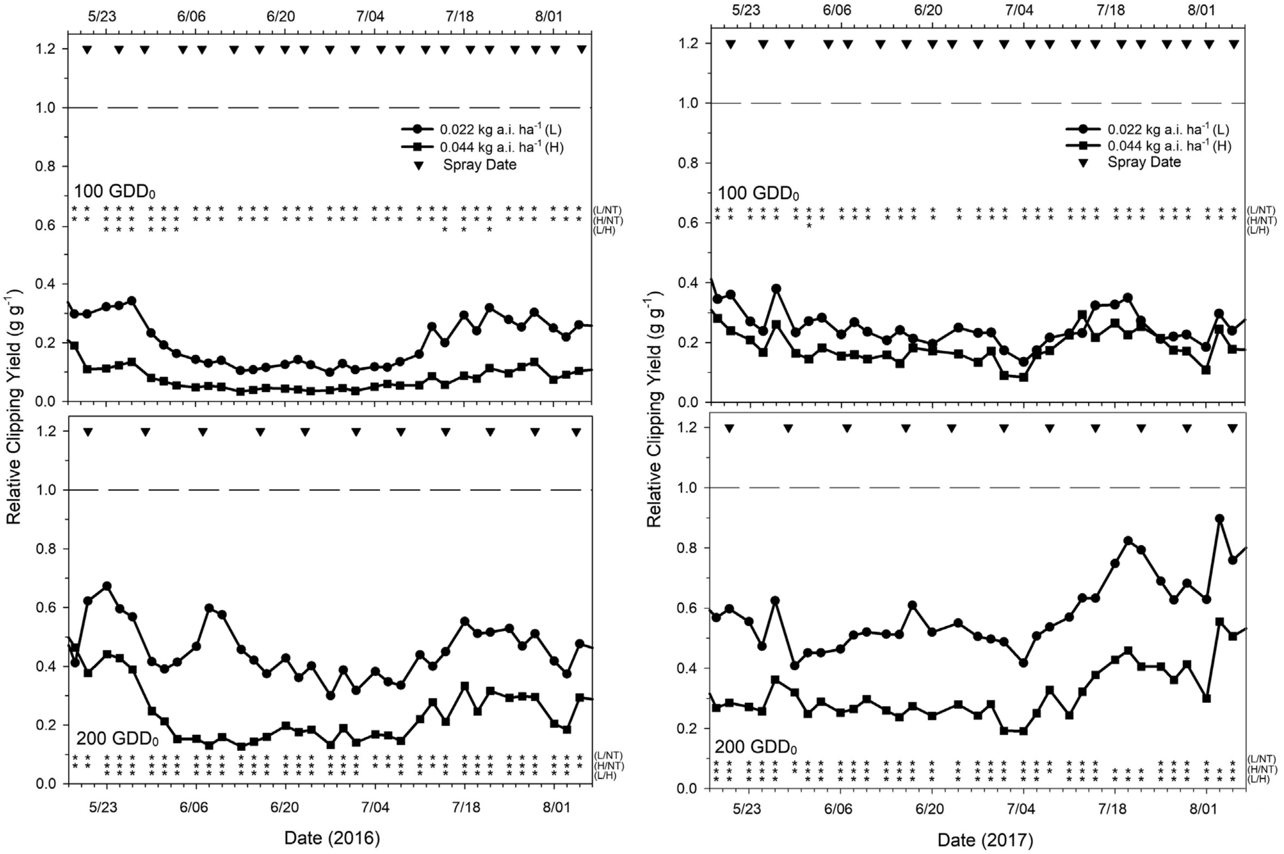

FIGURE 2 Relative clipping yield plotted by collection date for the application period (100- and 200-GDD_0 intervals), separated by year, interval, and rate. The graphs begin after the maximum suppression point (MSP) that followed the initial trinexapac-ethyl (TE) application and end on the date of the final TE application. For each graph, the top row of asterisks (L/NT) indicates if the low rate was significantly less than the nontreated on that collection date (according to Fisher's protected LSD with $\alpha = .05$), and the middle row of asterisks (H/NT) indicates if the high rate was significantly less than the nontreated. The bottom row (L/H) indicates if the low rate was significantly different from the high rate on that collection date

it is not practical for most turfgrass managers to reapply this often.

3.2.2 | 200 GDD_0

For the low rate, growth was significantly less than the nontreated on every collection date in 2016 and on all but four in 2017 (Figure 2). The high rate was significantly less than the nontreated on every collection date in both 2016 and 2017, and the high rate was significantly different from the low rate on every collection date, except for seven collections in 2016 and two in 2017. For the low rate, the average suppression was 55% in 2016 and 41% in 2017, whereas the average suppression for the high rate was 76% in 2016 and 68% in 2017 (Table 1).

Based on our other experiment (Brown et al., 2021), the 200-GDD_0 interval should occur before the MSP at 262 GDD_0. Supporting our hypothesis that reapplications before the MSP will provide more consistent turfgrass growth rates, the high rate resulted in daily growth ranging from 0.20–2.3 and from 0.40–2.6 g m^{-2} d^{-1} in 2016 and 2017, respectively, compared with the nontreated range of 1.2–6.0 and 1.3–5.2 g m^{-2} d^{-1} in 2016 and 2017, respectively (Figure 4). Given that TE rate did not affect duration to the MSP, we also expected that the low rate applied every 200 GDD_0 would maintain a consistent daily growth rate, though suppression magnitude would be less. For the low rate, growth ranged from 0.45–3.4 and from 0.50–3.4 g m^{-2} d^{-1} in 2016 and 2017, respectively.

The color ratings for the low rate were statistically equal to or greater than the nontreated by 21 DAIT for both years and were never considered unacceptable (Table 2). Color ratings for the high rate were significantly less than the nontreated until about 28 DAIT in both years. Although the color ratings for the high rate were never unacceptable in 2016, color remained unacceptable until 21 DAIT in 2017. After the discoloration subsided, color ratings were equal to or significantly higher than the nontreated for the remainder of the TE application period. Previous research

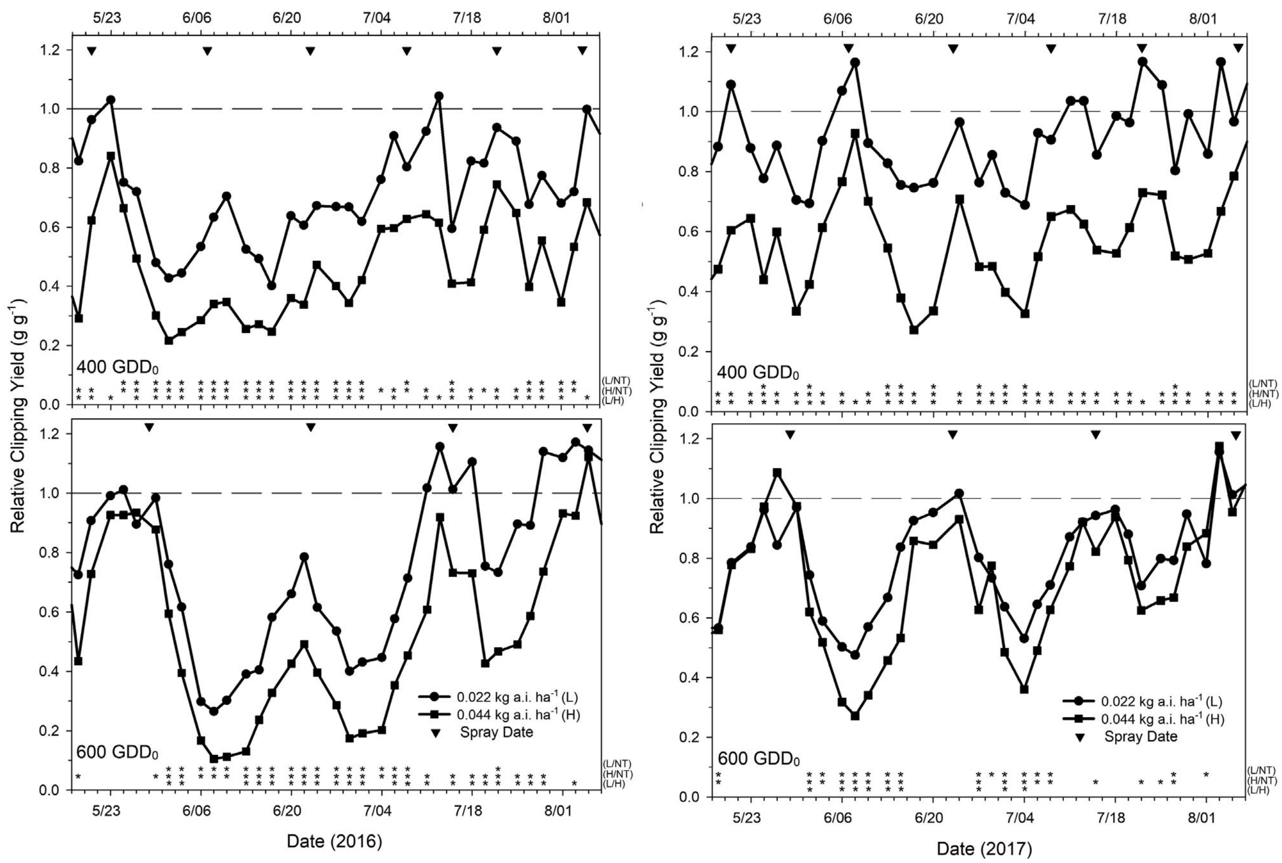

FIGURE 3 Relative clipping yield plotted by collection date for the application period (400- and 600-GDD$_0$ intervals). Separated by year, interval, and rate. The graphs begin after the maximum suppression point (MSP) that followed the initial trinexapac-ethyl (TE) application and end on the date of the final TE application. For each graph, the top row of asterisks (L/NT) indicates if the low rate was significantly less than the nontreated on that collection date (according to Fisher's protected LSD with $\alpha = .05$), and the middle row of asterisks (H/NT) indicates if the high rate was significantly less than the nontreated. The bottom row (L/H) indicates if the low rate was significantly different from the high rate on that collection date

also suggested that frequent TE applications at low rates will prevent phytotoxicity and still maintain suppression of ultra-dwarf bermudagrass and creeping bentgrass putting greens (McCullough et al., 2005a; McCullough, Liu, & McCarty, 2005b; McCullough, Liu, McCarty, & Toler, 2007).

3.2.3 | 400 GDD$_0$

The 400-GDD$_0$ interval occurs about 140 GDD$_0$ after the MSP, so we expected that both rates would result in fluctuating daily growth. For the low rate, clipping yield was not significantly different from the nontreated on 13 and 27 of the collection dates in 2016 and 2017, respectively (Figure 3). In contrast, the clipping yield for the high rate was significantly less than the nontreated on every collection date except for three in 2016 and three in 2017. Furthermore, the clipping yield of the high rate was significantly different from the low rate on every collection date in 2017 and all but five in 2016. The average suppression for the low rate was 28% in 2016 and 9% in 2017, compared with the high rate with an average suppression of 54% in 2016 and 43% in 2017 (Table 1).

For average suppression magnitude over the entire application period, the 200-GDD$_0$ (low rate) and 400-GDD$_0$ (high rate) intervals were not significantly different with a suppression magnitude of 55 vs. 54% in 2016 and 41 vs. 43% in 2017, respectively, which was expected given that the total applied TE was approximately the same. In contrast, when analyzed by collection date, the suppression magnitude of these two treatments was significantly different on 12 collection dates in 2016 and 7 in 2017. Thus, whereas the 400-GDD$_0$ high rate maintained the suppression phase, it yielded less consistent daily growth (Figure 4).

For both years, the color rating of the low rate was never significantly lower than the nontreated, though some discoloration did occur (Table 2). Similar to the 200-GDD$_0$ interval, the color rating for the high rate was significantly less than the nontreated until 28 DAIT in both years.

TABLE 2 Turfgrass color rating separated by year, treatment, and rating date

Turfgrass color ratings[a] (2016)							
Treatment		**DAIT[b,c]**					
Interval	**Rate**	**7**	**21**	**28**	**46**	**67**	**88**
100 GDD_0	0.022	6.2a	6.5ab	6.8a	8.0a	7.2a	8.0a
	0.044	5.8a	5.2c	5.5b	6.0c	7.0a	8.0a
200 GDD_0	0.022	6.2a	6.8ab	7.0a	8.0a	7.2a	8.0a
	0.044	6.0a	6.2b	6.5a	8.0a	7.5a	8.0a
400 GDD_0	0.022	6.0a	6.8ab	7.0a	8.0a	7.2a	8.0a
	0.044	5.8a	6.2b	6.8a	8.0a	7.2a	8.0a
600 GDD_0	0.022	6.2a	6.8ab	6.8a	8.0a	7.5a	8.0a
	0.044	6.5a	6.5ab	7.0a	8.0a	7.5a	8.0a
Nontreated	0	6.0a	7.0a	7.0a	7.0b	7.0a	7.0b
Turfgrass color ratings[a] (2017)							
Treatment		**DAIT[b,c]**					
Interval	**Rate**	**9**	**14**	**21**	**30**	**53**	**93**
100 GDD_0	0.022	5.8bc	5.2d	6.0a	7.8ab	8.0a	8.0a
	0.044	5.0d	4.0e	5.0c	6.8d	8.0a	8.0a
200 GDD_0	0.022	6.2ab	6.0bc	6.8a	8.0a	8.0a	8.0a
	0.044	5.2cd	4.5e	6.0b	7.5abc	8.0a	8.0a
400 GDD_0	0.022	6.8a	7.0a	7.0a	8.0a	8.0a	8.0a
	0.044	5.8bc	5.8cd	6.2b	8.0a	8.0a	8.0a
600 GDD_0	0.022	6.2ab	7.0a	7.0a	8.0a	7.2b	7.0b
	0.044	6.2ab	6.5ab	7.0a	7.2bcd	7.8a	8.0a
Nontreated	0	6.8a	7.0a	7.0a	7.0cd	7.0b	7.0b

Note. GDD_0, growing degree-days with a base temperature of 0 ˚C.
[a]A color rating of 6 was considered minimally acceptable and 9 was considered optimal turfgrass. [b]Days after initial treatment. [c]Column means not sharing a letter are significantly different according to Fisher's protected LSD (α = .05).

3.2.4 | 600 GDD_0

The clipping yield of the low rate was not significantly different from the nontreated on 18 and 19 collection dates in 2016 and 2017, respectively (Figure 3). The clipping yield of the high rate was not significantly different from the nontreated on 8 and 18 collection dates in 2016 and 2017, respectively, but it was significantly different from the low rate on 23 and 9 collection dates in 2016 and 2017, respectively. For the low rate, average suppression was only 24% in 2016 and 20% in 2017, whereas the high rate provided an average suppression of 46% in 2016 and 27% in 2017 (Table 1). Color ratings were never significantly lower than the nontreated for either rate (Table 2).

3.3 | Analysis of the postapplication period

As with the application period, relative clipping yield following the cessation of TE reapplications was significantly different for the two years, so results are presented by year. Additionally, GDD_0 interval, rate, and the GDD_0 interval × rate interaction were significant so treatments will again be discussed separately.

3.3.1 | Suppression duration

In 2016 and 2017, the MSP occurred for all treatments within ∼260 GDD_0 after the final TE application, which corroborates the results from Brown et al. (2021) (Figure 5). In contrast, for both years, the total duration of the suppression phase was shorter than expected for the high rate (Figure 5). For instance, in 2016, the suppression phase of the 400-GDD_0 (high rate) and 600-GDD_0 (high rate) ended within 420 GDD_0 after the final TE application. This was unexpected because we reported that suppression duration was over 1100 GDD_0 in August 2016 following a single TE application at the high rate (Brown et al., 2021). (The two experiments were conducted concurrently, so environmental conditions were the same.)

We propose two explanations for this conflict in suppression duration. First, TE efficacy may decrease as a GA_{20}

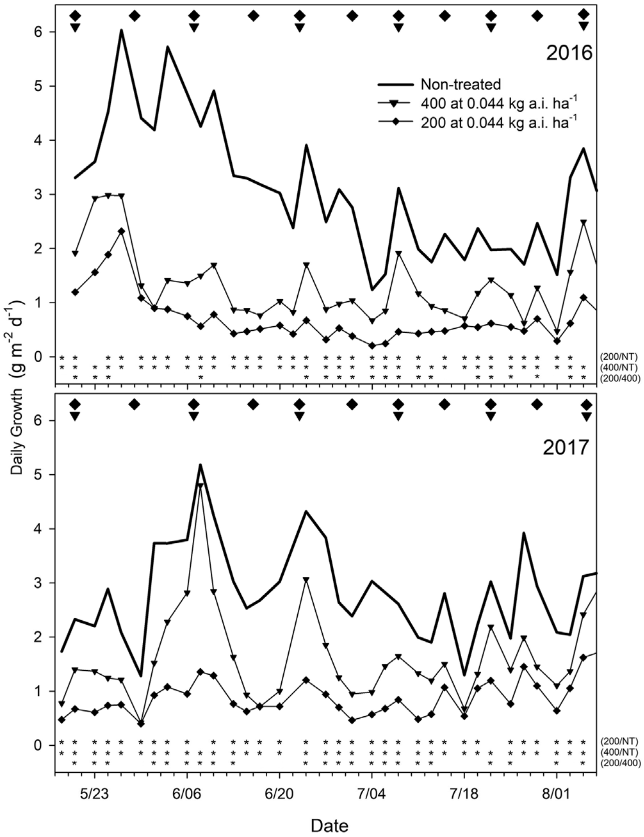

FIGURE 4 Daily growth plotted by collection date for the application period. The diamonds and triangles at the top of each graph represent spray dates for the 200- and 400-GDD_0 interval, respectively. The top row of asterisks (200/NT) indicates if the 200-GDD_0 interval was significantly less than the nontreated on that collection date (according to Fisher's protected LSD with $\alpha = .05$), and the middle row of asterisks (400/NT) indicates if the 400-GDD_0 interval was significantly less than the nontreated. The bottom row (200/400) indicates if the 200-GDD_0 interval at the high rate was significantly different from 400-GDD_0 interval at the high rate on that collection date

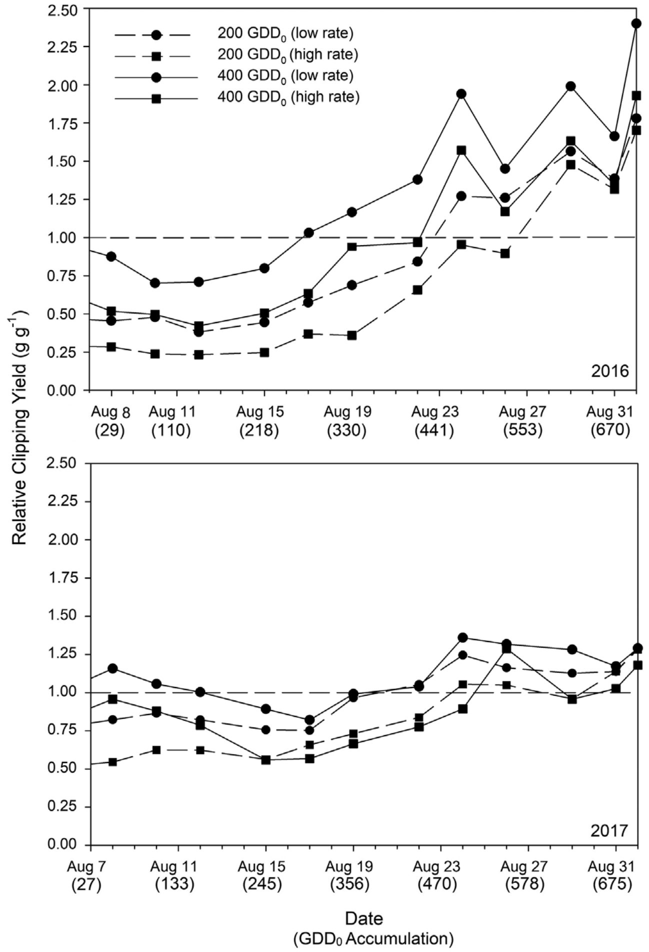

FIGURE 5 Relative clipping yield plotted by collection date for the postapplication period. Total growing degree-days with a base temperature of 0 ˚C (GDD_0) accumulation after the final trinexapac-ethyl (TE) application is listed under the collection date on the *x*-axis. This graph begins on the collection date following the final TE application and ends on the final collection date, but analysis of the postapplication period only includes data starting with 17 and 16 Aug. in 2016 and 2017, respectively, and continuing through the final collection date

backlog forms following sequential applications (Tan & Qian, 2003). All else being equal, an increased GA_{20} concentration would increase the likelihood of the catalyzation of GA_{20} to GA_1, and the result would be a quicker return to the nontreated growth rate. Second, as a flaw in data collection method, increased tiller density of the treated plots compared with the nontreated may exaggerate the turfgrass growth rate, giving the appearance of a shortened suppression duration (Lickfeldt, Gardner, Branham, & Voigt, 2001). Although tiller density was not quantified in this experiment, previous research suggested that repeated TE applications may significantly increase tiller density (Ervin & Koski, 1998; Ervin & Koski, 2001). Future plant growth regulator research should measure linear growth rate on a per-tiller basis to avoid the issue of differing tiller density between the treated and nontreated plots.

3.3.2 | Accelerated growth

Accelerated growth (*rebound*) may occur after the suppression phase, but this phenomenon varies with cultivar, temperature, and TE rate (Beasley, Branham, & Spomer, 2007; Fagerness & Yelverton, 2000; Kreuser & Soldat, 2011). Rebound is hypothesized to be the result of accumulated GA_{20}, a nonbioactive GA, being quickly converted to GA_1, the first bioactive GA, as trinexapac acid is degraded (King et al., 1997). Two weeks after a second TE application on Kentucky bluegrass, GA_{20} concentration was increased 146%, whereas there was a 47% decrease in GA_1 concentration (Tan & Qian, 2003). We did not report significant rebound in our experiment with a single TE application on ultradwarf bermudagrass (Brown et al., 2021), which agreed

TABLE 3 Average relative clipping yield over the postapplication period

Treatment		Average relative clipping yield[a,b]	
Interval	Rate	2016	2017
100 GDD_0	0.022	1.27bc	0.87c
	0.044	0.85e	0.94c
200 GDD_0	0.022	1.17cd	1.09ab
	0.044	0.97de	0.96bc
400 GDD_0	0.022	1.62a	1.16a
	0.044	1.27bc	0.91c
600 GDD_0	0.022	1.49ab	0.91c
	0.044	1.28bc	0.88c
Nontreated	0	1.00cde	1.00bc

Note. GDD_0, growing degree-days with a base temperature of 0 ˚C.
[a]This includes collection dates beginning at the maximum suppression point after the final TE application and ending on the last collection date (17 Aug. to 2 Sept. 2016; 16 Aug. to 1 Sept. 2017). [b]Column means not sharing a letter are significantly different according to Fisher's protected LSD (α = .05).

with previous research (Reasor et al., 2018). To date, no research has reported rebound following TE applications on ultradwarf bermudagrass putting greens. In contrast, the following results suggest that rebound may occur after the cessation of repeated applications.

For both years, no treatment was ever significantly higher than the nontreated when analyzed by individual collection date. However, in 2016, average suppression magnitude during the postapplication period was significantly higher than the nontreated for the 400-GDD_0 (low rate) and 600-GDD_0 (low rate). The 400-GDD_0 (low rate) had the greatest increase in growth with an average of 62% more than the nontreated (Table 3), and it peaked at 140% more on the last collection date (Figure 5). In 2017, only the 400-GDD_0 (low rate) was significantly higher than the nontreated during the postapplication period, with only 16% more growth.

Given the discrepancy between years and experiments, the extent of rebound following the cessation of sequential TE applications on ultradwarf putting greens remains questionable. As previously mentioned, increased tiller density for the treated plots may have caused this apparent increase in turfgrass growth rate. Until future research measures turfgrass growth rate on a per-tiller basis and for a longer period after the final TE reapplication, turfgrass managers should be wary of ending TE reapplications midseason.

4 | CONCLUSIONS

Given that TE rate does not affect duration to the MSP, we conclude that reapplying TE before ~260 GDD_0 will maintain the suppression phase of ultradwarf bermudagrass putting greens for all commonly used TE rates (0.01 to 0.05 kg a.i. ha^{-1}). Future research should test a reapplication interval closer to 260 GDD_0, but a 200-GDD_0 interval will ensure a consistent turfgrass growth rate and acceptable quality. Applying more frequently than 200 GDD_0 may cause unacceptable discoloration, especially at higher TE rates, and applying less frequently will yield fluctuating growth rates and the potential of rebound growth.

Most turfgrass managers have limited flexibility in the scheduling of maintenance practices, so a strict GDD reapplication interval may be difficult to implement. However, we suggest that a GDD schedule can be used in combination with a calendar schedule. For example, TE could be reapplied every 7 d only if 200 GDD_0 has accumulated since the previous application (or if forecasts indicate that this threshold will be crossed soon). Or, perhaps even more important, GDD could be used to ensure that reapplications occur frequently enough to prevent potential rebound growth. Future research should test a GDD_0 reapplication schedule in different climates and find ways to reduce phytotoxicity following initial applications.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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