Creating GDD Models for Commonly Applied Plant Growth Regulators

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INTRODUCTION

Growing degree day models have been shown to predict the performance of the plant growth regulator (PGR) trinexapac-ethyl (Primo Maxx). These models are effective because metabolism or degradation of PGRs was found to be directly related to air temperature. Relative clipping yield of turfgrasses treated with trinexapac-ethyl followed a sinewave model with a period of growth suppression followed by a period of growth enhancement, hereafter called rebound, with respect to non-treated cool-season putting greens. A recent Twitter poll found that nearly 50% of respondents now use GDD models to apply PGRs to their turfgrass despite the lack of GDD models for other anti-gibberellin PGRs.

The objectives of this research were to i) determine if GDD models could predict performance of other PGRs, ii) investigate the impact application rate on PGR performance, and iii) determine optimum GDD re-application intervals for each PGR.

METHODS

This research was conducted on a 'V8' creeping bentgrass putting green at the JSA Turf Research Facility in Mead, NE during 2015. The green was constructed to USGA recommendations for putting green construction, mowed 6 d wk^{-1} at 0.120", irrigated to 80% of pET, and fertilized weekly with 0.1 lbs N/1000 ft^2 from urea fertilizer. Topdressing and cultivation was avoided during the growing season to avoid impacting on data collection. Diseases were controlled curatively with fungicides; DMI fungicides were not used. A wetting agent (Revolution, Aquatrols) was applied monthly to ensure uniform water distribution.

The experimental design was a RCBD with three replicate blocks. Plots measured 5'x5.' Treatments included commonly applied PGRs at various application rates and a non-treated control (Table 1). All PGR treatments were re-applied every 1000 GDD Celsius (base temperature of 0°C) except for one of the Anuew treatments that was re-applied every 300 GDD. Temperature data was obtained from an on-site weather station and the GDD model was reset to 0 GDD when PGRs were re-applied. Applications were made with a CO_2-powered backpack sprayer equipped with three TeeJet XR8006 flat fan nozzles. The sprayer output volume was calibrated to 2.0 gal/1000 ft^2 at 40 psi. The first application of PGRs occurred on 8 May 2015 for PGR treatments except the Cutless 50W treatments which were first applied on 19 May 2015. The final PGR applications occurred in August.

Clippings were collected approximately three times a week (T, W, F) by mowing one pass down the center of each pass with a Toro GM1000 walking greensmower. Clippings were then dried, cleaned of sand debris, and weighed. To calculate relative clipping production, mean dry clipping weights for each PGR treatment was divided by the mean dry clipping weight of the non-treated control for each collection date.

Relative clipping yield was modeled relative to GDDs following PGR application with waveform regression in SigmaPlot 13. The model was a two parameter sinewave model:

$$\textit{Relative yield} = A*\sin(2\pi*GDD/B+\pi) + y_{int}$$

Briefly explained, relative yield (g g^{-1}) is a function of the amplitude of growth suppression/rebound (*A*) times the sine of 2π times GDDs accumulated from the most recent PGR application divide by period (*B).* The period is the duration of time, in GDDs, required for the suppression and rebound response to occur. The intercept term (y_{int}) was the average of all the data points within each particular model. Student's *t-tests* were used to compare the amplitude and period terms for the 10 PGR models with α=0.05. The ideal GDD interval for each PGR was determined by dividing the period by 3. This corresponds with a point 33% between the point of maximum growth suppression and the suppression/rebound transition point. Statistical significance of the period and ideal GDD re-application interval were therefore identical as the mean value and SEM terms were both divided by 3.

RESULTS AND DISCUSSION

Performance of all the PGRs was successfully modeled with GDD models. The adjusted R^2 values of the 10 models ranged from 0.62 to 0.19 with higher application rates having higher R^2 values (Table 2). All 1000 GDD PGR treatments induced a growth suppression phase followed by a rebound phase (Figs. 1, 3-11). The magnitude of the growth suppression/rebound was dependent upon PGR product and application rate (Table 3). The high-labeled rates increased the magnitude of suppression/rebound compared to the low-labeled rates for Trimmit 2SC and Musketeer treatments. There was a trend of more growth suppression at the high-labeled rates of Legacy and Cutless 50W, but differences were not significant. Anuew was only evaluated at one application rate because 2014 research from the University of Wisconsin-Madison indicated that the magnitude of growth suppression was independent from application rate. More research should be conducted to confirm that finding on cool-season golf putting greens.

PGR product impacted the duration of PGR performance. All the treatments except for the low-labeled rate of Cutless 50W had a statistically similar period (ranging from 804 to 943 GDD). The low-labeled rate of Cutless 50W elicited the weakest growth response and there was a high degree of model variance. This reduced our ability to detect difference between the low-label Cutless 50W (*B=616 GDD)* and the high rate of Cutless 50W *(B=821)*. Although there was a trend of longer PGR duration (period) with higher application rate, increasing from the low-label to high-label rate did not statistical alter the effective control of any of the products except for the low rate of Cutless 50W. It should be noted that the low-labeled rate of Cutless 50W delivers much less active ingredient compared to the other PGRs tests with respect to their high-label rates.

Another interesting phenomenon that was observed after the rebound phase was a second phase of growth suppression. This likely occurs as the result of positive and negative feedback mechanisms within the plant. Our hypothesis is that several subsequent suppression and rebound phases occur after the initial suppression and rebound phase as the plant returns back to a “normal” level of gibberellin production/degradation. It is likely that the magnitude of the subsequent suppression and rebound phases decays with time until the effects of the PGR have completely dissipated. This has implications on the type of sinewave model used for future research. It’s likely that an amplitude damped sinewave regression model be more appropriate to understand how PGRs affect plant growth over the long-term. In practice, this tweak to the model likely has a minimal effect on the data presented here because the suppression and rebound growth phases were fairly strong and symmetric. Additionally, understanding the impact PGRs may have on growth several weeks to months after the last application is not practical because PGRs are very frequently applied to maintain growth suppression.

Early GDD model research with trinexapac-ethyl found that the ideal re-application interval should be 33% between the point of maximum growth suppression and the transition from suppression to rebound. Due to the symmetric nature of a sinewave model, that point is exactly one-third of the model’s period (duration). Therefore, both the period for each model, and associated error term, was divided by three to calculate the ideal re-application interval. The concept was further proven through a comparison of the 300 GDD Anuew treatment (Fig. 2) with the results of the 1000 GDD Anuew model. It was determined that the period of the Anuew model was 841 GDD and the ideal re-application interval should be 280 GDD. Application of Anuew every 300 GDD provided consistent growth suppression until 280 GDD at which point clipping yield began to return to the level of the non-treated control (Fig.2). Re-applying Anuew a minimum of 20 to 30 GDD sooner likely would have maintained growth suppression.

The ideal re-application interval for most PGR treatments ranged from 270 to 310 GDD; they were not statistically different. This indicates that these PGRs are metabolized at roughly the same rate within the plant. There is also no practical difference between these PGRs because 40 GDD can be less than two days during mid-summer. The low-labeled rate of Cutless 50W had an ideal interval of 210 GDD which was likely due to the relatively low amount of active ingredient applied. Much like the early trinexapac-ethyl research, increasing PGR application rate is not an effective way to increase the duration of control with a PGR. Doubling or tripling rate increased the duration of control by only a few days or less; certainly not worth two to three times the expense. The more efficient way to sustain season-long growth suppression is re-apply PGRs based on GDD models which account for PGR breakdown.

TABLES AND FIGURES

Table 1. The PGR treatments evaluated in 2015.

Plant growth regulator	Active ingredients (%)	Application rate	GDD re-application interval (base °C)
Non-treated control	Na	Na	Na
Anuew	Prohexadione-Ca (27.5%)	0.184 wt. oz./1000 ft^2	300
Anuew	Prohexadione-Ca (27.5%)	0.184 wt. oz./1000 ft^2	1000
Trimmit 2SC	Paclobutrazol (22.9%)	0.125 fl. oz./1000 ft^2	1000
Trimmit 2SC	Paclobutrazol (22.9%)	0.250 fl. oz./1000 ft^2	1000
Trimmit 2SC	Paclobutrazol (22.9%)	0.375 fl. oz./1000 ft^2	1000
Cutless 50W	Flurprimidol (50%)	0.046 wt. oz./1000 ft^2	1000
Cutless 50W	Flurprimidol (50%)	0.184 wt. oz./1000 ft^2	1000
Legacy	Flurprimidol (13.26%) Trinexapac-ethyl (5.00%)	0.110 fl. oz./1000 ft^2	1000
Legacy	Flurprimidol (13.26%) Trinexapac-ethyl (5.00%)	0.220 fl. oz./1000 ft^2	1000
Musketeer	Flurprimidol (5.6%) Paclobutrazol (5.6%) Trinexapac-ethyl (1.4%)	0.275 fl. oz./1000 ft^2	1000
Musketeer	Flurprimidol (5.6%) Paclobutrazol (5.6%) Trinexapac-ethyl (1.4%)	0.510 fl. oz./1000 ft^2	1000

Table 2. Sinewave regression model results and parameter estimates for the various PGR products and application rates.

Plant growth regulator	Application rate	Adjusted r^2	Model Significance	Amplitude (A)	Period (B)	Intercept (y_{int})
	oz./1000 ft^2			$g\ g^{-1}$	GDD	$g\ g^{-1}$
Anuew	0.184	0.620	<0.001	0.341^{***}	841^{***}	0.988^{***}
Trimmit 2SC	0.125	0.407	<0.001	0.272^{***}	832^{***}	0.966^{***}
Trimmit 2SC	0.250	0.530	<0.001	0.301^{***}	899^{***}	0.899^{***}
Trimmit 2SC	0.375	0.725	<0.001	0.396^{***}	943^{***}	0.865^{***}
Cutless 50W	0.046	0.194	0.052	0.137^{**}	616^{***}	0.932^{***}
Cutless 50W	0.184	0.321	0.007	0.181^{**}	821^{***}	0.864^{***}
Legacy	0.110	0.371	<0.001	0.204^{***}	804^{***}	0.950^{***}
Legacy	0.220	0.505	<0.001	0.269^{***}	911^{***}	0.861^{***}
Musketeer	0.275	0.420	<0.001	0.238^{***}	861^{***}	0.955^{***}
Musketeer	0.510	0.566	<0.001	0.376^{***}	880^{***}	0.928^{***}

** Model coefficient significant at $p<0.010$

*** Model coefficient significant at $p<0.001$

Table 3. Impact of PGR product and application rate on the magnitude of the suppression and rebound growth phases.

Plant growth regulator	Application rate	Maximum relative growth suppression & rebound	Means separation
	oz./1000 ft^2	% of control	
Trimmit 2SC	0.375	0.396	a
Musketeer	0.510	0.376	ab
Anuew	0.184	0.341	ab
Trimmit 2SC	0.250	0.301	abc
Trimmit 2SC	0.125	0.272	bc
Legacy	0.220	0.269	bc
Musketeer	0.275	0.238	c
Legacy	0.110	0.204	cd
Cutless 50W	0.184	0.181	cd
Cutless 50W	0.046	0.137	d

Table 4. Impact of PGR product and application rate on the duration of growth alteration and the ideal re-application interval to sustain season-long growth suppression.

Plant growth regulator	Application rate	Model period (PGR duration)	Ideal GDD re-application interval	Means separation
	oz./1000 ft^2	---GDD---		
Trimmit 2SC	0.375	943	310	a
Legacy	0.220	911	300	ab
Trimmit 2SC	0.250	899	300	ab
Musketeer	0.510	880	290	ab
Musketeer	0.275	861	290	ab
Anuew	0.184	841	280	ab
Trimmit 2SC	0.125	832	280	ab
Cutless 50W	0.184	821	270	abc
Legacy	0.110	804	270	ab
Cutless 50W	0.046	616	210	c

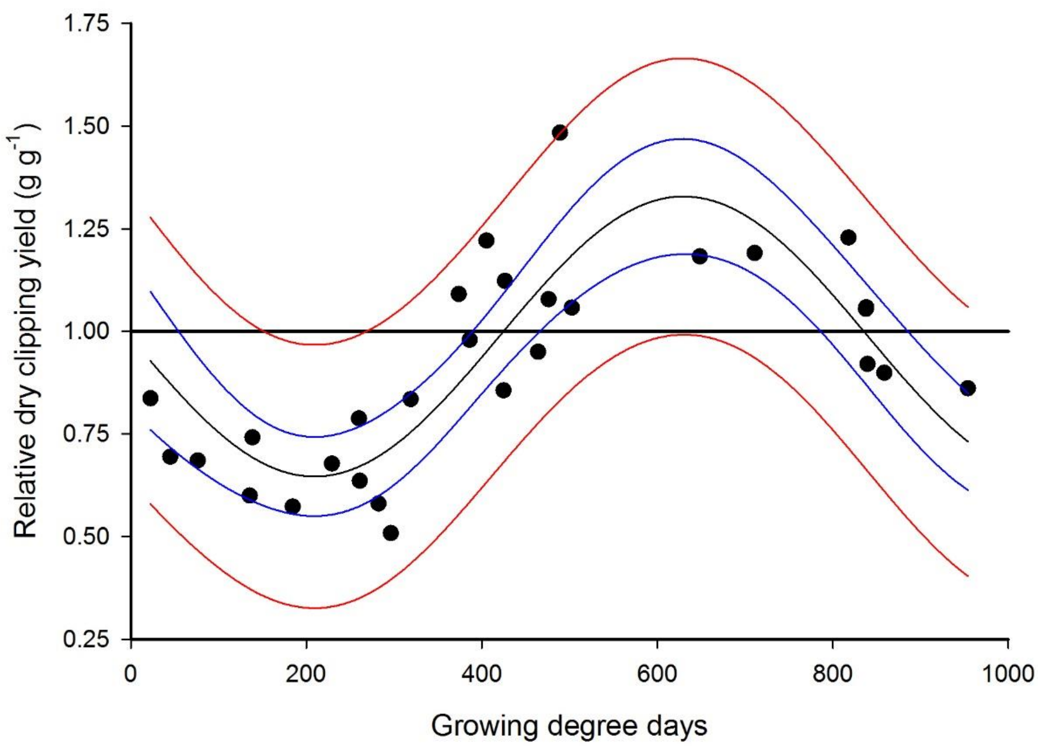

Figure 1. Anuew PGR applied at 0.184 wt. oz./1000 ft^2 every 1000 GDD.

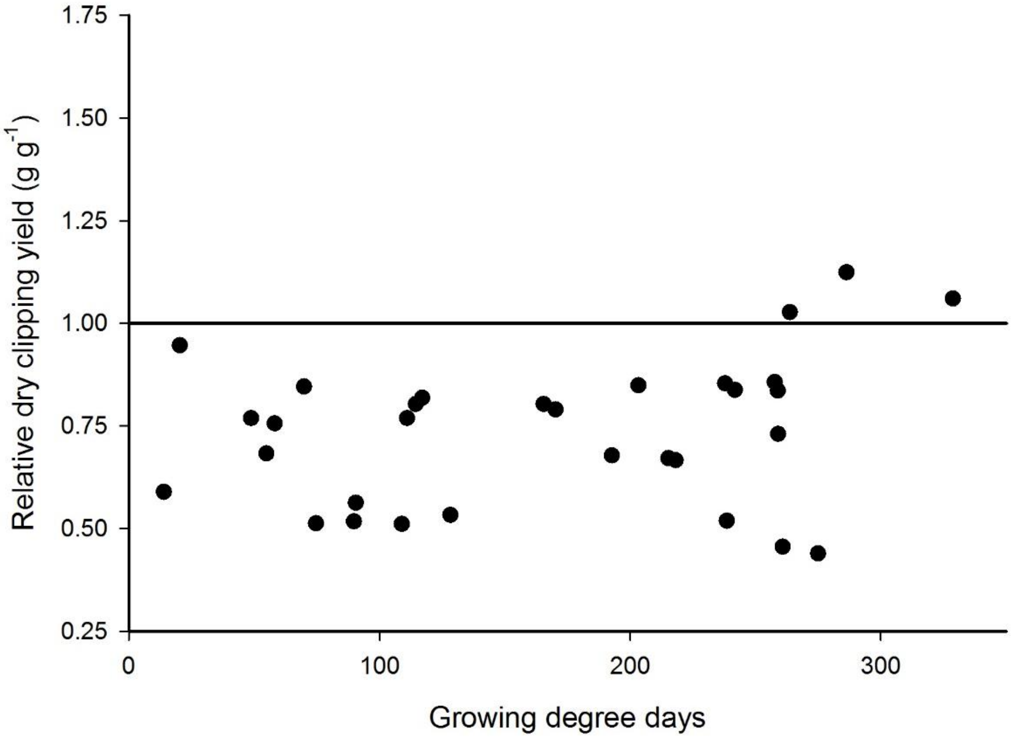

Figure 2. Anuew PGR applied at 0.184 wt. oz./1000 ft^2 every 300 GDD. The model for Anuew indicates the ideal PGR re-application interval for Anuew would be 280 GDD. The 300 GDD re-application interval supports that interval with some breakthrough after 280 GDD.

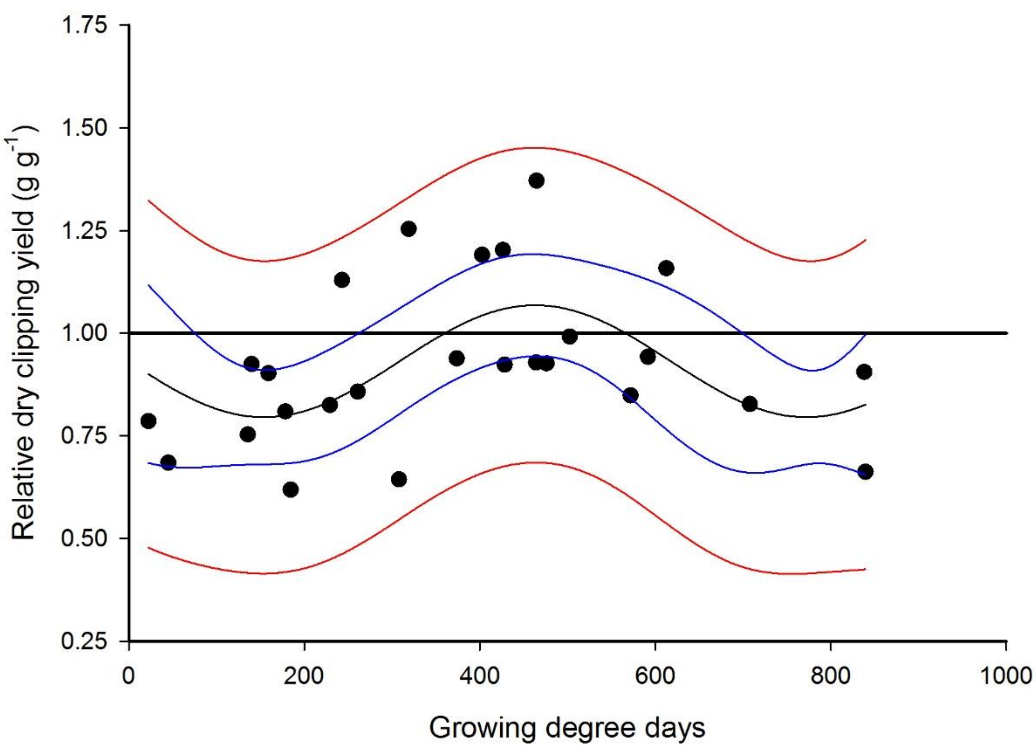

Figure 3. Low-labeled rate of Cutless 50W PGR (0.046 wt. oz./1000 ft^2 every 1000 GDD).

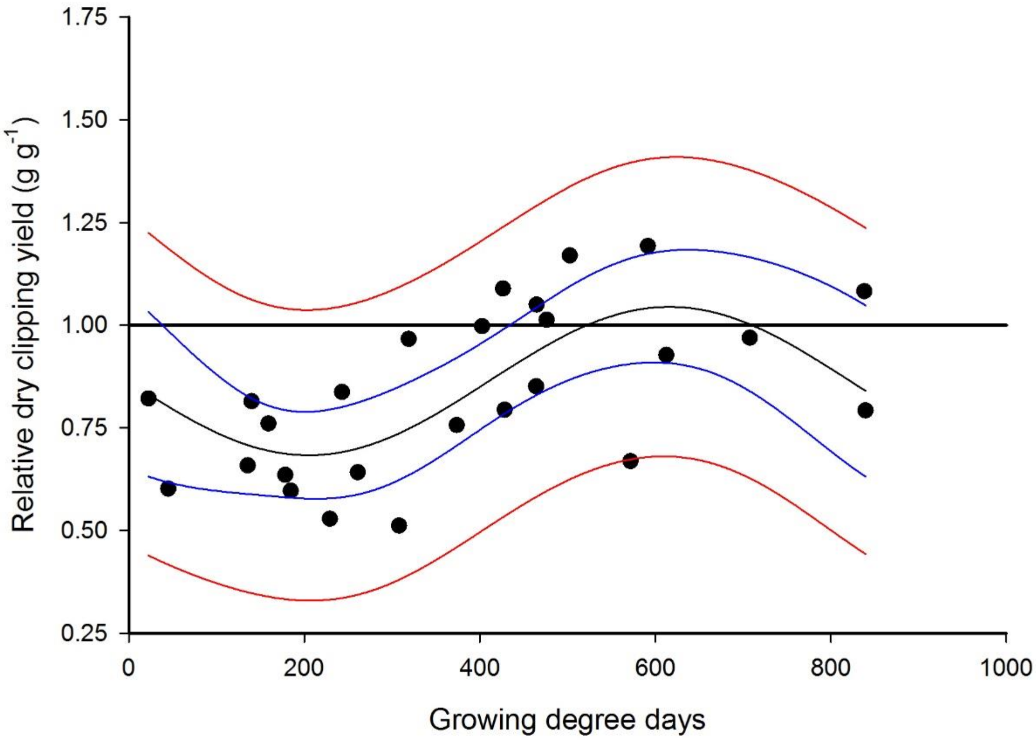

Figure 4. High-labeled rate of Cutless 50W PGR (0.184 wt. oz./1000 ft^2 every 1000 GDD).

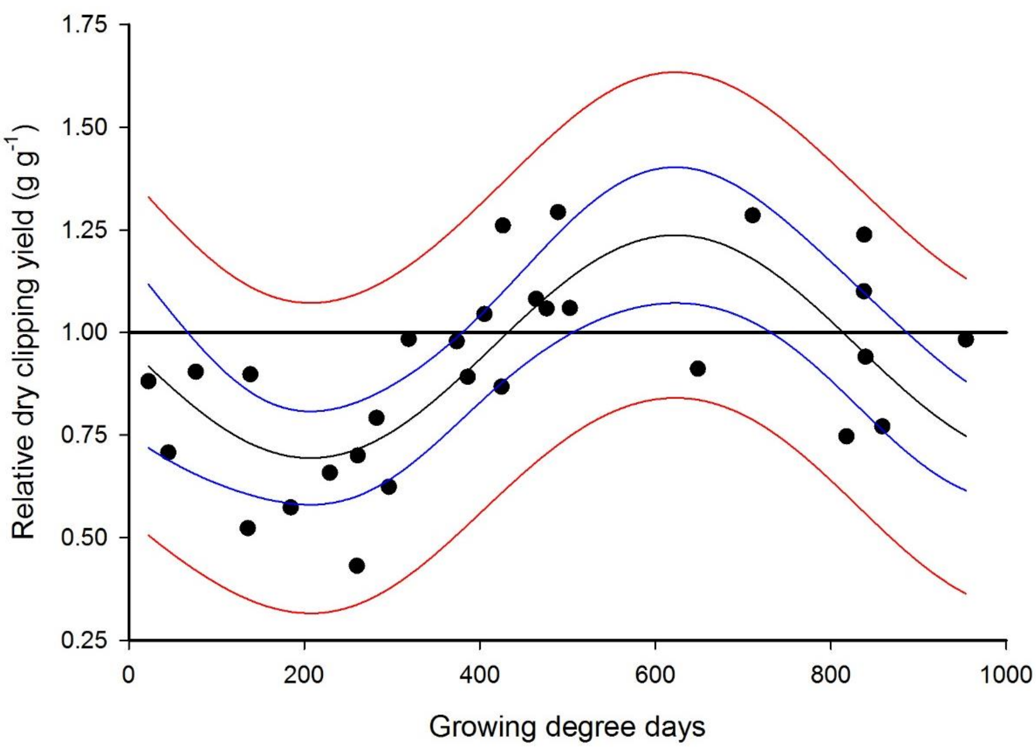

Figure 5. Low-labeled rate of Trimmit 2SC PGR (0.125 fl. oz./1000 ft^2 every 1000 GDD).

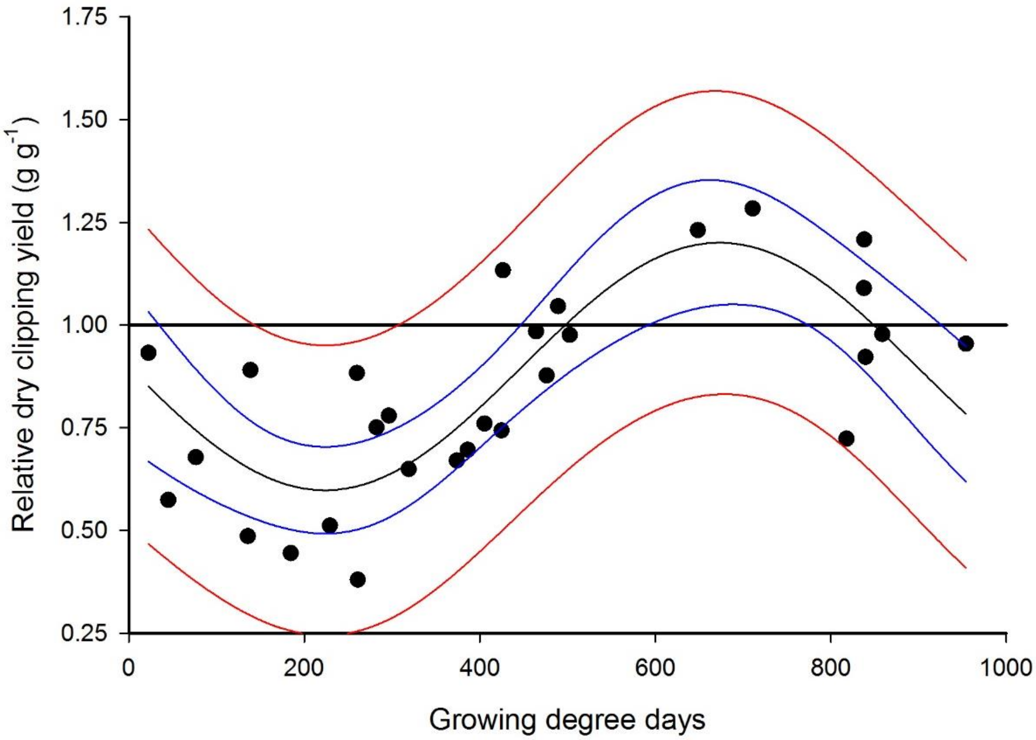

Figure 6. Mid-labeled rate of Trimmit 2SC PGR (0.250 fl. oz./1000 ft^2 every 1000 GDD).

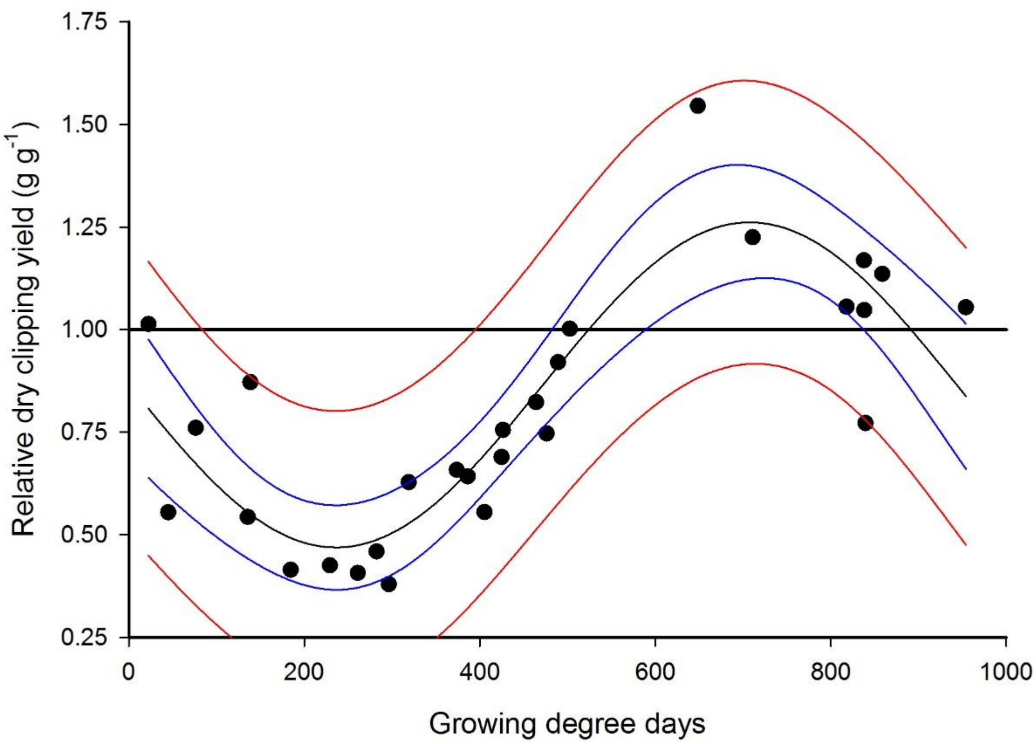

Figure 7. High-labeled rate of Trimmit 2SC PGR (0.375 fl. oz./1000 ft^2 every 1000 GDD).

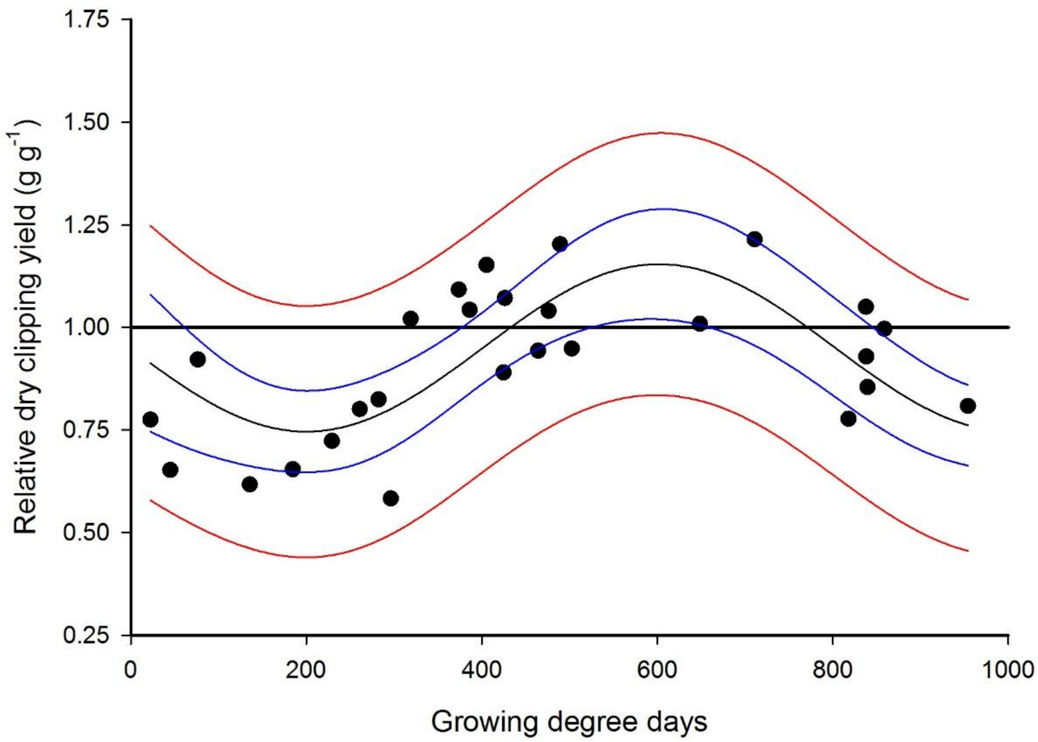

Figure 8. Low-labeled rate of Legacy PGR (0.110 fl. oz./1000 ft^2 every 1000 GDD).

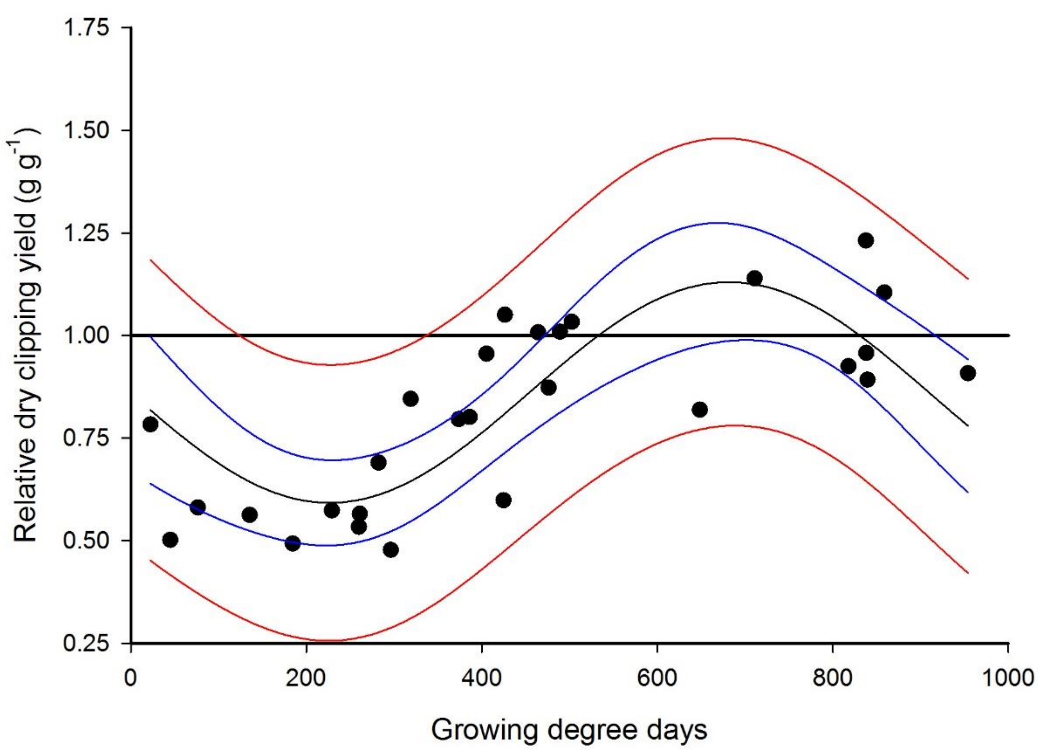

Figure 9. High-labeled rate of Legacy PGR (0.220 fl. oz./1000 ft^2 every 1000 GDD).

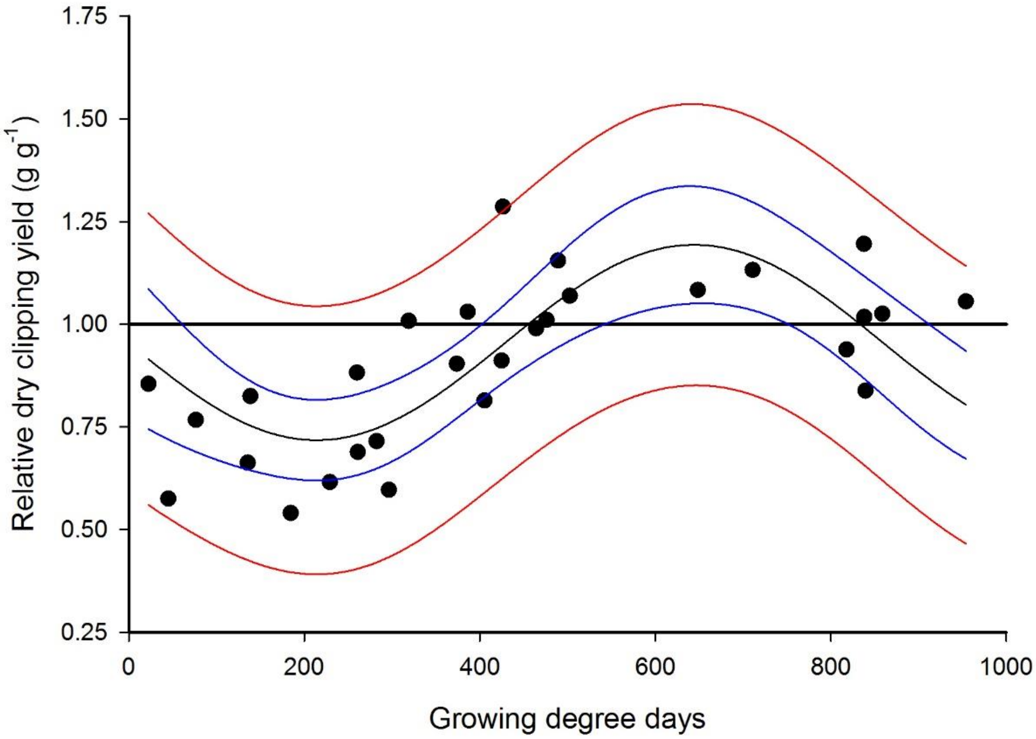

Figure 10. Low-labeled rate of Musketeer PGR (0.275 fl. oz./1000 ft^2 every 1000 GDD).

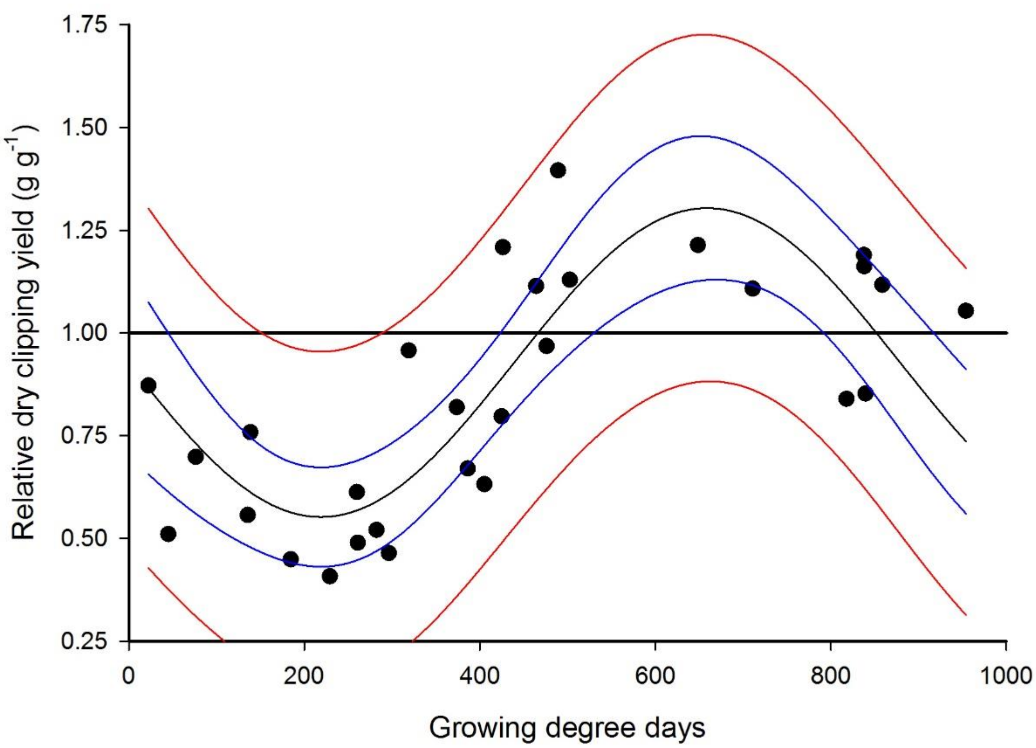

Figure 11. High-labeled rate of Musketeer PGR (0.510 fl. oz./1000 ft^2 every 1000 GDD).