Precise PGR applications on greens

To suppress turfgrass yield throughout the season, use growing degree days to schedule Primo Maxx applications.

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Over the past two decades, repeated applications of plant growth regulators (PGRs) have become a staple of putting green management. Golf course superintendents use products such as Primo Maxx (trinexapac-ethyl, Syngenta), Trimmit (paclobutrazol, Syngenta) and Cutless (flurprimidol, SePro) to reduce clipping yield, increase ball-roll distance and enhance turfgrass visual quality through increased color and stand density (3). Although use of plant growth regulators is widespread, superintendents employ a variety of application rates and reapplication frequencies, especially on cool-season greens.

Suppression, rebound and efficacy

Plant growth regulators alter clipping yield in two distinct phases: the suppression phase followed by the rebound phase (4). The suppression phase occurs after a PGR application and is associated with lower clipping yield, better visual quality and greater carbohydrate reserves than nontreated turfgrass (5,6). The rebound phase follows the suppression phase. During the rebound, clipping yield is greater than nontreated turf while other beneficial responses (that is, turfgrass color and carbohydrate levels) begin to decline (9). The duration and magnitude of the suppression phase depends on turfgrass species, application rate, management practices and environmental conditions.

Over the past 10 years, researchers and superintendents alike have noted decreased PGR efficacy, especially from Primo Maxx, during the heat of summer on cool-season greens. Researchers (1) found that Primo Maxx and Trimmit metabolism (or degradation within the plant) is directly related to air temperature, and they therefore concluded Primo Maxx needs to be applied more frequently during hot weather and less frequently during cool weather. This means that calendar-based reapplication intervals are not an efficient way to sustain yield suppression.

Growing degree day models

The alternative to imprecise, calendar-based applications is to apply PGRs based on plant metabolism or rate of PGR breakdown. Growing degree day (GDD) models provide a simple way to estimate plant metabolism since PGR degradation is enhanced as temperature increases. To calculate GDD, the daily high and low air temperatures are averaged together, subtracted from a base temperature where metabolism is minimal, and added to values from the previous GDD total. The objective of this research was to determine whether a GDD model could predict trinexapac-ethyl degradation on creeping bentgrass (*Agrostis stolonifera*) greens. The ultimate goal was to determine a GDD interval that would sustain the yield suppression (and desirable responses such as quality enhancement) during the entire growing season.

Two experiments were conducted over the course of three growing seasons at the O.J. Noer Turfgrass Research and Education Facility in Madison, Wis. In 2008, a GDD model for Primo Maxx was developed on a creeping bentgrass green. The model was verified in 2009 and 2010 on a different creeping bentgrass green at two different application rates.

GDD model development

Methods

An L-93 creeping bentgrass green was irrigated to 80% of potential evapotranspiration daily, fertilized with 0.1 pound nitrogen/1,000 square feet (4.88 kilograms/hectare) weekly and mowed at 0.120 inch (3 millimeters) six days a week with a

Toro Greensmaster 1000. The Primo Maxx treatments consisted of five reapplication intervals of 100-, 200-, 400- and 800-GDD thresholds, a four-week calendar-based interval suggested by the product label and a non-treated control for comparison.

Growing degree days were calculated in degrees Celsius with a base temperature of 0 C. The GDD calculations began after Primo Maxx was first applied. Once the threshold was surpassed for a particular treatment, Primo Maxx was reapplied and the GDD model was reset to zero.

Each treatment was replicated four times. Primo Maxx was applied at the same rate (0.125 fluid ounces/1,000 square feet or 5.5 ounces/acre [0.40 liters/hectare]) for all treatments with a four-nozzle (TeeJet XR 11004) spray boom calibrated to deliver 2 gallons/1,000 square feet (90 gallons/acre [814.9 liters/hectare]). Applications began on June 22 and continued to Aug. 19, 2008.

Clippings were collected five days a week, cleaned of sand debris, dried at 140 F and weighed. Average clipping dry mass for each treatment was then divided by the average dry clipping mass of the control to determine the relative clipping yield. The models were developed by plotting relative clipping yield by cumulative GDD following Primo Maxx application. The data were then subject to regression analysis. Visual quality was rated every two weeks on a scale of 1 to 9, where 1 represents completely dead, 6 represents minimally acceptable and 9 represents highest putting green turfgrass quality.

Results

The weather in the summer of 2008 was average for Madison, Wis. The daily average air temperature ranged from 52 F to 80 F (11 C to 26 C). Application of Primo Maxx resulted in a range of clipping yield responses from 61% to 126% of the control (values less than 100% indicate yield suppression; values greater than 100% indicate yield enhancement or rebound). The four-week interval as well as the 400- and 800-GDD reapplication intervals did not suppress clipping yield during the entire study (Figure 1). Instead, clipping yield fluctuated between the suppression and rebound phases.

Model. Because the 400-GDD, 800-GDD and four-week reapplication intervals produced both the suppression and rebound phase, the data were combined to create the model (Figure 2). The resulting GDD model was statistically significant and generalized how Primo Maxx affects

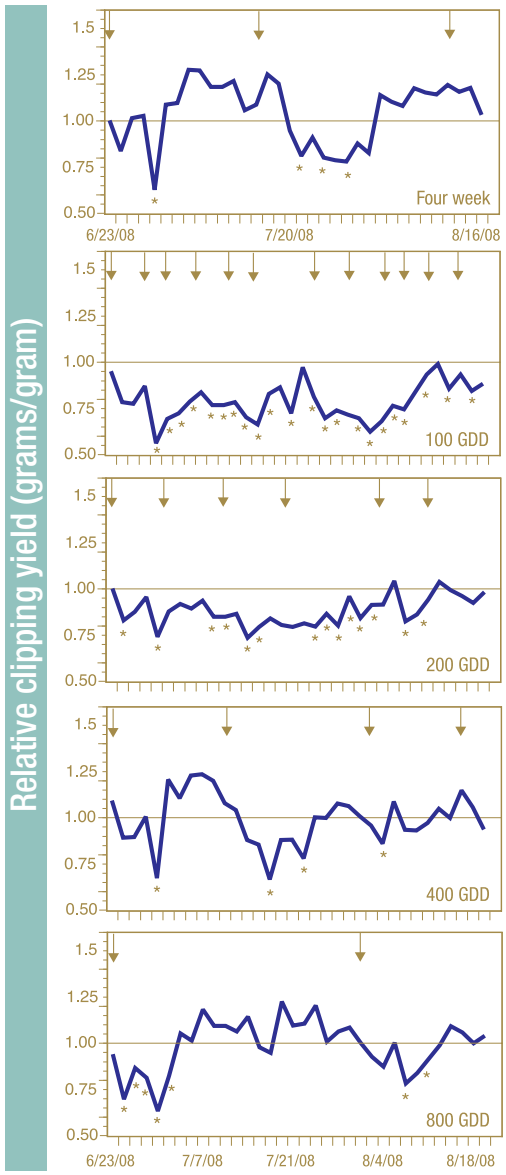

Figure 1. The role of Primo Maxx reapplication interval on creeping bentgrass putting green clipping yield. Relative clipping yield values less than 1 represent growth suppression, whereas values greater than 1 represent growth enhancement or rebound. Reapplication of Primo Maxx every four weeks did not sustain season-long yield suppression. The 100-GDD and 200-GDD reapplication interval prevented the rebound phase. Growing degree days were calculated in degrees Celsius with a base temperature of 0 C. Asterisks indicate days when clipping yield was statistically less than the control; arrows show Primo Maxx applications.

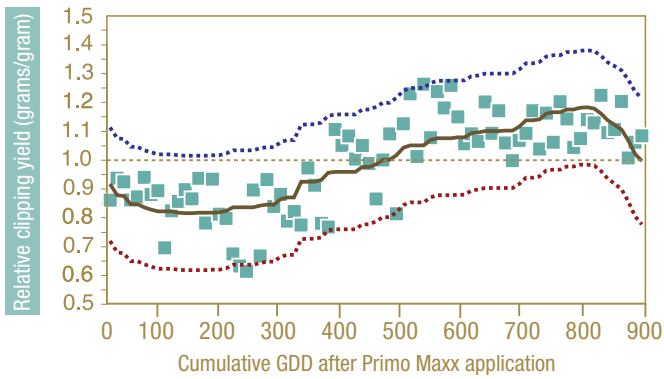

Figure 2. Creeping bentgrass response to Primo Maxx application during 2008. The suppression phase follows Primo Maxx application and continues to approximately 300 GDD. The rebound phase follows from 300 GDD to 800 GDD. Application of Primo Maxx every 200 GDD prevents the rebound phase from occurring. Growing degree days were calculated in degrees Celsius.

Total clipping yield and visual quality, 2008

Reapplication interval†	Total clipping yield (grams/square meter)	Average visual quality rating‡
100 GDD	53.5a	8.2a
200 GDD	59.4ab	7.8b
400 GDD	65.2bc	7.8b
800 GDD	65.2bc	7.6bc
Four weeks	68.8c	7.8b
Non-treated control	67.06c	7.4c

†GDD, growing degree days.

‡Visual quality was rated on a scale of 1 to 9, where ≥6 is acceptable.

Table 1. Total clipping yield and average turfgrass visual quality rating during the 2008 growing season. Only the 100-GDD and 200-GDD (base 0 C) intervals reduced clipping yield compared to the non-treated control plots. Yield suppression from the other, less frequent Primo Maxx application rates, including the four-week interval, was cancelled out by the rebound growth phase. Sustained yield suppression resulted in the highest turfgrass visual quality rating.

The research was carried out at the O.J. Noer Turfgrass Research and Education Facility in Madison, Wis. **Photos by Bill Kreuser**

clipping yield of creeping bentgrass greens. Average peak yield suppression occurred 120 GDD after Primo Maxx application and was typically 18% less than the control. Following peak suppression, relative clipping yield transitioned to the rebound phase, which began 300 GDD after application. The rebound phase lasted until 800 GDD with maximum rebound 540 GDD after Primo Maxx application.

Yield suppression. Application of Primo Maxx every 100 or 200 GDD sustained season-long yield suppression. The more frequent 100-GDD application interval suppressed clipping yield by 20% compared to 11% for the 200-GDD reapplication interval. Although the 100-GDD reapplication interval provided slightly greater yield suppression, total clipping production during the study was statistically similar to the 200-GDD interval (Table 1). Additionally, a 100-GDD interval may not be practical in summer heat. For example, when the daily average air temperature is 68 F (20 C), the 100-GDD reapplication threshold would be surpassed in five days. When temperatures become favorable for diseases such as *Pythium* blight, 100 GDD can occur in three days or less.

Clipping yield. Total clipping yield was calculated for each treatment in 2008 (Table 1). The 400- and 800-GDD interval, as well as the four-week interval, had clipping yield totals similar to that of the non-treated control. This occurred because growth enhancement during the rebound phase cancelled out growth suppression following Primo Maxx application. The 100- and 200-GDD intervals, however, had a lower total clipping yield compared to the control. The positive consequences of reduced clipping yield included increased turfgrass visual quality rating (Table 1) and less nutrient removal during mowing. Our current research also indicates there is a small but sustained increase in ball-roll distance (green speed).

GDD model validation

Methods

To verify the 2008 results, the GDD model was evaluated on a different creeping bentgrass green during 2009 and 2010. Management practices for the Penncross green used for validation were similar to those on the green used for model development. Treatments consisted of a non-treated control and Primo Maxx applied at 0.125, and 0.250 fluid ounce/1,000 square feet (5.5 and 11.0 fluid ounces/acre or 0.40 and 0.80 liter/hectare) every 200 GDD Celsius or every four weeks. Each of the six treatments was replicated four times. Treatments began in April and continued

Applying Primo Maxx every 200 GDD enhanced turfgrass visual quality throughout the growing season. The plot in the center was not treated with Primo Maxx.

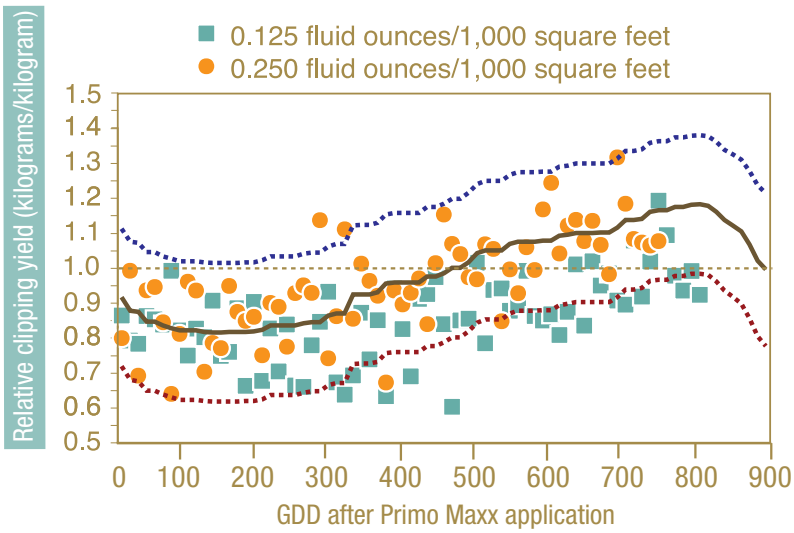

Figure 3. The model from 2008 (the solid black line) was validated with data collected from a different creeping bentgrass putting green during 2009 and 2010. The dashed lines represent the 95% confidence interval for any observation. The data followed the 2008 model regardless of Primo Maxx application rate. Increasing application rate is not an effective way to increase the duration of magnitude of clipping yield suppression.

into October each year. Clippings were collected three days a week, and visual quality was rated every two weeks.

Results

Average air temperature was below average in 2009 and above average in 2010, which was ideal for validating our GDD model. As in 2008, the four-week reapplication interval did not sustain season-long yield suppression regardless of application rate or year. Relative clipping yield for the four-week treatment followed the GDD model developed in 2008 (Figure 3). Increased application rate did not increase the amount of growth suppression or the length of the suppression phase. Both application rates (0.125 and 0.250 ounce/1,000 square feet) reduced clipping yield by an average maximum of 18% for approximately 300 GDD. Growth was then enhanced by an average maximum of 18% during the rebound phase for the next 500 GDD.

As in 2008, reapplication of Primo Maxx every 200 GDD resulted in season-long yield suppression. Average suppression ranged from 11% to 20% regardless of application rate. Clearly, increasing Primo Maxx application rate is not a successful option to sustain clipping yield suppression during the heat of the summer. As in 2008, applying Primo Maxx every 200 GDD soon resulted in greater turfgrass quality than the control.

Research discussion and implications

Basing PGR applications on plant metabolism rather than calendar intervals increases application precision and results in season-long yield suppression. Applying Primo Maxx every 200 GDD during the three years of this study reduced the clipping yield of creeping bentgrass greens by approximately 20%. These results have been further verified on two creeping bentgrass/annual bluegrass (*Poa annua*) greens in Ithaca, N.Y. (Kreuser and Rossi, unpublished data, 2011).

For reference, 200 GDD Celsius would occur in 20 days when average daily temperature is 50 F (high air temperatures near 60 F and low air temperatures near 40 F). The 200-GDD reapplication interval shortens to 20 days as daily average air temperature approaches 70 F. During weather conducive to *Pythium* blight, 200 GDD can elapse in five days or less.

Increasing Primo Maxx application rate did not lengthen the duration or magnitude of growth suppression phase on creeping bentgrass greens. Therefore, using high application rates to coun-

Clippings were collected by mowing one pass down the center of each plot. Clippings were then brushed into a paper bag, dried and weighed to determine clipping yield relative to a non-treated control plot. **Photo by Tom Schwab**

ter Primo Maxx metabolism is not effective, and Primo Maxx should be reapplied more frequently.

Growing degree days were calculated in degrees Celsius during this study because we found the base temperature to be 0 C (Figure 2). This was advantageous because we did not have to subtract a base temperature from the daily average air temperature to calculate the GDD. Alternatively, a 200-GDD Celsius threshold is equivalent to 360-GDD Fahrenheit with a base temperature of 32 F. An Excel spreadsheet to track GDD accumulation is available at http://turf.wisc.edu under the GDD Maps tab.

The Primo GDD threshold developed in this study is specific to creeping bentgrass greens. Although annual bluegrass and creeping bentgrass show similar responses, bermudagrass (*Cynodon* species) is much more sensitive to Primo Maxx. Applying Primo Maxx to bermudagrass greens suppressed clipping yield by more than 50% for four or more weeks (4,8), but applying Primo Maxx every 200 GDD could be detrimental to the green. Applying Primo Maxx to a Kentucky bluegrass athletic field plot every 200 GDD proved to be too frequent and led to 95% yield suppression and decreased wear tolerance (Kreuser, unpublished data, 2011). Additional experimentation is needed to accurately determine the ideal Primo Maxx reapplication interval for these situations.

Aside from decreasing clipping yield, season-long clipping yield suppression can offer many sustained secondary benefits. For example, ongoing research at Cornell University found that 200-GDD applications of Primo Maxx can increase ball roll distance by 4 to 8 inches (10.2-20.3 centimeters). Researchers have also found that turfgrass color, sugar content and shade tolerance are enhanced during the suppression growth phase (2,5,6,10). Applying Primo every 200 GDD would sustain these responses during the entire growing season. Finally, we found that 200-GDD Primo Maxx applications reduced creeping bentgrass nitrogen requirements by about 25% because less nitrogen fertilizer is removed during mowing (7).

Conclusions

Applying Primo Maxx to creeping bentgrass greens every four weeks, as recommended by the product label, not only did not maintain clipping yield suppression, but also caused clipping yield to fluctuate between suppression and rebound. Simply increasing the labeled application rate did not lengthen the duration of clipping suppression. Estimation of Primo Maxx metabolism with a GDD model successfully predicted the duration and magnitude of both the suppression and rebound

phase. Season-long clipping yield suppression was sustained when Primo Maxx was reapplied every 200 GDD Celsius (base 0 C). These results were repeated for three years, on two different creeping bentgrass greens in Madison, Wis. Increased Primo Maxx application rate did not further lengthen the duration or increase the amount of yield suppression. Therefore, increased reapplication frequency, and not increased application rate, are required to sustain yield suppression when Primo metabolism is greatest during the heat of summer. Growing degree day models can provide an easy and effective tool to schedule Primo Maxx applications to creeping bentgrass greens.

The research says

- Applying Primo Maxx at four-week intervals resulted in periods of yield suppression followed by rebound, particularly in summer heat.
- PGR degradation increases as temperature increases, so a GDD model should result in more consistent clipping yield suppression.
- Applying Primo Maxx every 200 GDD sustained season-long suppression on creeping bentgrass and enhanced turf color, sugar content and shade tolerance.
- Higher application rates are not as effective as more frequent applications.

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Literature cited

1. Beasley, J.S., and B.E. Branham. 2005. Analysis of paclobutrazol and trinexapac acid in turfgrass clippings. *International Turfgrass Society Research Journal* 10:1170-1175.
2. Ervin, E.H., and A.J. Koski. 1998. Growth responses of *Lolium perenne* to trinexapac-ethyl. *HortScience* 33:1200-1202.
3. Ervin, E.H., and X. Zhang. 2008. Applied physiology of natural and synthetic plant growth regulators on turfgrasses. p. 171-200. *In:* M. Pessarakli, ed. Handbook of turfgrass management and physiology. CRC Press, Boca Raton, Fla.
4. Fagerness, M.J., and F.H. Yelverton. 2000. Tissue production and quality of 'Tifway' bermudagrass as affected by seasonal application patterns of trinexapac-ethyl. *Crop Science* 40:493-497.
5. Han, S.W., T.W. Fermanian, J.A. Juvik and L.A. Spomer. 1998. Growth retardant effects on visual quality and nonstructural carbohydrates of creeping bentgrass. *HortScience* 33:1197-1199.
6. Han, S., T.W. Fermanian, J.A. Juvik and L.A. Spomer. 2004. Total nonstructural carbohydrate storage in creeping bentgrass treated with trinexapac-ethyl. *HortScience* 39:1461-1464.
7. Kreuser, W.C., and D.J. Soldat. 2012. Frequent trinexapac-ethyl applications reduce nitrogen requirements of creeping bentgrass golf putting greens. *Crop Science* 52(3):1348-1357.
8. McCullough, P.E., H. Liu, L.B. McCarty and J.E. Toler. 2007. Trinexapac-ethyl application regimens influence growth, quality, and performance of bermudagrass and creeping bentgrass putting greens. *Crop Science* 47:2138-2144.
9. Richie, W.E., R.L. Green and F. Merino. 2001. Trinexapac-ethyl does not increase total nonstructural carbohydrate content in leaves, crowns, and roots of tall fescue. *HortScience* 36:772-775.
10. Stier, J.C., J.N. Rodgers III, J.R. Crum and P.E. Rieke. 1999. Effects of flurprimidol on Kentucky bluegrass under reduced irradiance. *Crop Science* 39:1423-1430.

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