Effective Use of Plant Growth Regulators on Golf Putting Greens

To maximize the potential of plant growth regulators, growing degree-day models offer a simple and effective way to estimate PGR performance.

BY BILL KREUSER, PH.D.

Mowing is the most labor- and fuel-intensive practice associated with turfgrass management and is a major component of most golf course management budgets. As a result, turfgrass managers have tried to reduce mowing requirements for decades. USGA Green Section agronomists first reported hormone growth regulators could reduce turfgrass clipping yield in the 1940s (Cornman and Bengtson, 1940). By the mid-20th century, cell division inhibitors such as maleic hydrazide and mefluidide were commercially available plant growth regulators (PGRs) for use on turfgrass. While these products were revolutionary, their use was still limited to low-maintenance turf because they can sometimes be phytotoxic. An article published in *The Bull Sheet* (anonymous, 1959) stated, "Ten years from now you will be able to sit on a lawn that needs no mowing and reach up to pick a normal sized peach from the low branches of a dwarf tree. This will be possible because within 10 years we will have an 'anti-gibberellin.'" While the first part of that statement has yet to be seen, gibberellic acid (GA) inhibiting growth regulators have definitely changed how we manage fine turfgrasses. GA inhibiting PGRs reduce clipping yield, provide good year-round safety, and promote a number of secondary benefits ranging from increased leaf color to increased stress tolerance and reduced nutrient requirements. Today, GA inhibiting PGRs like trinexapac-ethyl, flurprimidol, and paclobutrazol are staples of putting green management programs around the world.

After nearly 80 years of PGR turf research and despite widespread adoption by the turfgrass industry, there still seems to be an element of mystery or uncertainty behind the use of PGRs — especially when PGRs are applied to golf greens. It's relatively easy to figure out if a fungicide or herbicide is working — are diseases or weeds present? If yes, then another application is probably required. However, determining the efficacy of PGRs isn't as obvious. Often the only way for golf course superintendents to judge the effectiveness of a PGR program is to receive daily reports on how much grass is being mowed. While this method may be easy, it typically is not very accurate. Day-to-day variation in clipping yield can dwarf changes in clipping yield that result from PGRs (Fig. 1), making it very difficult for golf course superintendents to visually estimate PGR effectiveness. Ultimately, the difficulty in determining PGR effectiveness has led to a wide range of PGR application rates and frequencies, with little concrete data to measure performance in the field.

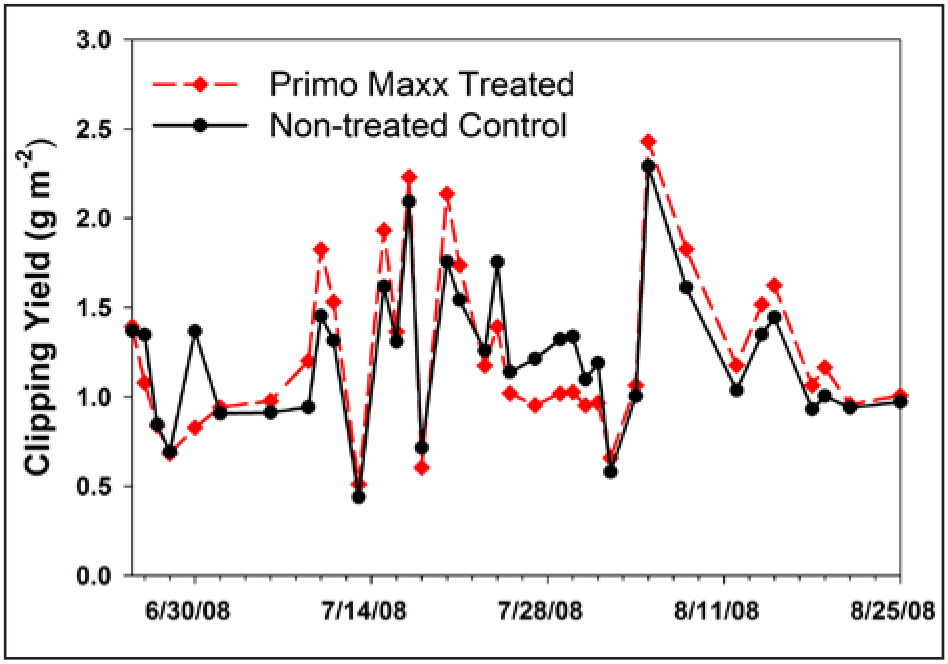

Figure 1. Fluctuations in actual clipping yield of a creeping bentgrass green. The red line represents plots treated with trinexapac-ethyl and the black represents the control. Day-to-day fluctuations in clipping yield were more extreme than changes resulting from PGR application.

PGRS OF PUTTING GREEN MANAGEMENT

By definition, a PGR is any compound, natural or synthetic, that alters plant growth or development, including plant hormones, herbicides, growth inhibitors, and even biostimulants. Plant growth regulators in turf are grouped into six classes, class A to class F (Table 1). While class A and class B PGRs most commonly are associated with putting green maintenance, all PGR classes have a role in most management

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Table 1
Plant growth regulator chemical classes, modes of action, and common examples used on putting greens

PGR Class	Mode of Action	Common Example and Trade Name
A	Late gibberellic acid inhibitor	Trinexapac-ethyl (Primo® Maxx, Syngenta), prohexadione-Ca (Anuew™, Nufarm)
B	Early gibberellic acid inhibitor	Flurprimidol (Cutless® MEC, SePro), paclobutrazol (Trimmit® 2SC, Syngenta)
C	Cell division inhibitor	Mefluidide (Embark®, PBI/Gordon)
D	Herbicide	Methiozolin (PoaCure®, Moghu Research Center), glyphosate (Roundup®, Monsato)
E	Phytohormone	Ethephon (Proxy®, Bayer Environmental Science)
F	Natural growth regulator	Seaweed extracts, humic acids

programs. For example, mefluidide (Embark®, PBI/Gordon) and ethephon (Proxy®, Bayer Environmental Science) are class C and class E PGRs used to control annual bluegrass (*Poa annua*) seedhead production in spring. Herbicides like methiozolin (PoaCure®, Moghu Research Center) are class D PGRs used to control annual bluegrass but also reduce creeping bentgrass clipping yield (Hoisington, 2013). Furthermore, many golf course superintendents apply humic acids and seaweed extracts — class F PGRs — in an effort to improve putting green performance during summer stress. Still, most golf course superintendents envision GA inhibitors when talking about growth regulators on greens, and those products will be the focus of this article.

The gibberellic acid inhibitors that are routinely applied to cool- and warm-season putting greens include trinexapac-ethyl, flurprimidol, and paclobutrazol. In 2015, prohexadione-calcium will be released as a fourth GA inhibitor available in the turf market. All four PGRs work by limiting the production of GA, the plant hormone that causes leaf cells to elongate. Class A PGRs inhibit GA biosynthesis near the end pathway, while class B PGRs inhibit GA biosynthesis earlier in the pathway. Class A PGRs are absorbed by the foliage, quickly rain fast, and reduce clipping yield across a range of spray volumes (Fagerness and Penner 1998a and 1998b). Class B PGRs are root absorbed and should be lightly watered into the soil after application.

Gibberellic acid inhibitors affect clipping yield in two distinct phases (Fig. 2). Clipping yield is first reduced during the suppression of GA, which immediately follows PGR application. After a period of time, relative clipping yield increases and then exceeds clipping yield of non-treated turf (Fig. 2). Fagerness and Yelverton (2000) first described this period of enhanced clipping yield in bermudagrass and called it "post-inhibition growth enhancement." Today, this phase is more frequently referred to as the "rebound phase" and has been observed in many turf species. The rebound phase is thought to occur because GA procurers and carbohydrates build up during the suppression phase, which causes a rapid increase in clipping yield once the PGRs are metabolized or removed during mowing. Turf managers should try to avoid the rebound phase to maximize the positive benefits related to PGRs applied to greens.

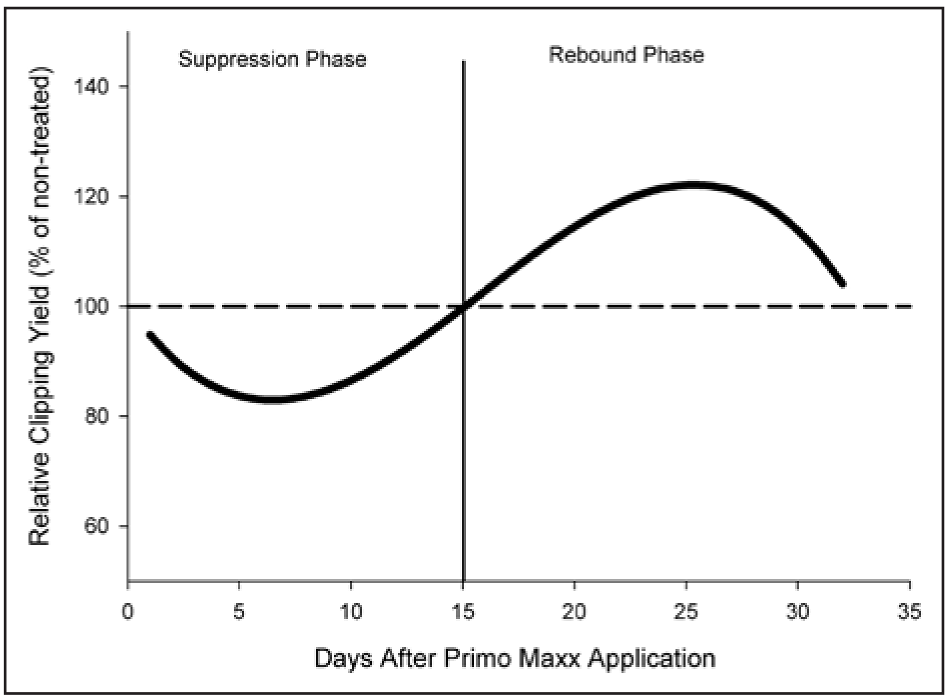

Figure 2. Gibberellic acid inhibitors affect growth in two phases. The first phase is growth suppression. The second phase is a rebound phase where clipping yield is greater than untreated turfgrass.

Table 2
The influence of trinexapac-ethyl application rate and reapplication frequency on magnitude and duration of growth suppression in various turfgrass species

Turfgrass Species and Mowing Height *Common name, inches*	Application Rate *fl. oz./acre*	Reapplication Frequency *Weeks*	Growth Suppression *% of control*	Approximate Duration of Growth Suppression *Weeks*	Reference
Creeping bentgrass, 0.13	5.5	4	20%	2	McCullough et al., 2006
Creeping bentgrass, 0.13	2.2, 3.3, 5.5	1, 2, 3	20-40%	3	McCullough et al., 2007
Kentucky bluegrass, 1.18	5.5	4-6	20%	4-6	Stier and Rogers, 2001
Kentucky bluegrass, 1.30	5.5	4	50%	4	Tan and Qian, 2003
Kentucky bluegrass, 1.25	15, 32, 64	none	44-73%	4-5*	Beasley and Branahm., 2007
Rough bluegrass, 3.15	32	6	55-80%	6	Gardner and Wherley, 2005
Sheep fescue, 3.15	32	6	35-50%	6	Gardner and Wherley, 2005
St. Augustinegrass, 3.00	15, 32	2, 4	50%	4	McCarty et al., 2004
Supina bluegrass, 1.18	5.5	4-6	60%	4-6	Stier and Rogers, 2001
Tall fescue, 1.50	32	none	44-77%	4	Richie et al., 2001
Tall fescue, 3.15	32	6	58-76%	6	Gardner and Wherley, 2005
TifEagle Bermudagrass, 0.13	5.5	4	60%	3	McCullough et al., 2007
Tifway Bermudagrass, 0.63	7.7, 12.1	4	60%	4	Fagerness and Yelverton, 2000
Tifway Bermudagrass, 1.00	12.1	4	50%	4	Fagerness et al., 2004
Zoysiagrass, 0.47	5.5, 11, 21	4, 8, 12	25, 27, 0%	4-6	Qian and Engelke, 1999

*Duration dependent on summer or fall season

At labeled rates, GA inhibitors typically suppress clipping yield by 50 percent for four weeks in most grasses (Table 2). The notable exceptions are class A PGRs applied to cool-season golf greens. McCullough et al. (2006) first showed that trinexapac-ethyl (Primo® Maxx, Syngenta) reduced clipping yield by 20 percent for two weeks on creeping bentgrass putting green when applied at 5.5 fluid ounces/acre (0.125 fluid ounce/1,000 square feet). In a follow-up study, McCullough et al. (2007) reported that the trinexapac-ethyl application rate did not affect the amount of clipping yield suppression on creeping bentgrass putting greens. More frequent application intervals were needed to sustain consistent growth suppression. In contrast, clipping yield was reduced by 55 percent for a period of four weeks on a Tifway bermudagrass putting green in that same study. Preliminary research at the University of Nebraska and University of Wisconsin found that prohexadione-Ca (Anuew™, NuFarm), another class A PGR, also reduced clipping yield by approximately 20 percent (Obear and Kreuser, 2014; Soldat, 2014).

AVOID THE REBOUND WITH GROWING DEGREE-DAYS (GDD)

In the early 2000s, many golf course superintendents reported trinexapac-ethyl didn't last as long during summer, and many thought the turf was becom-

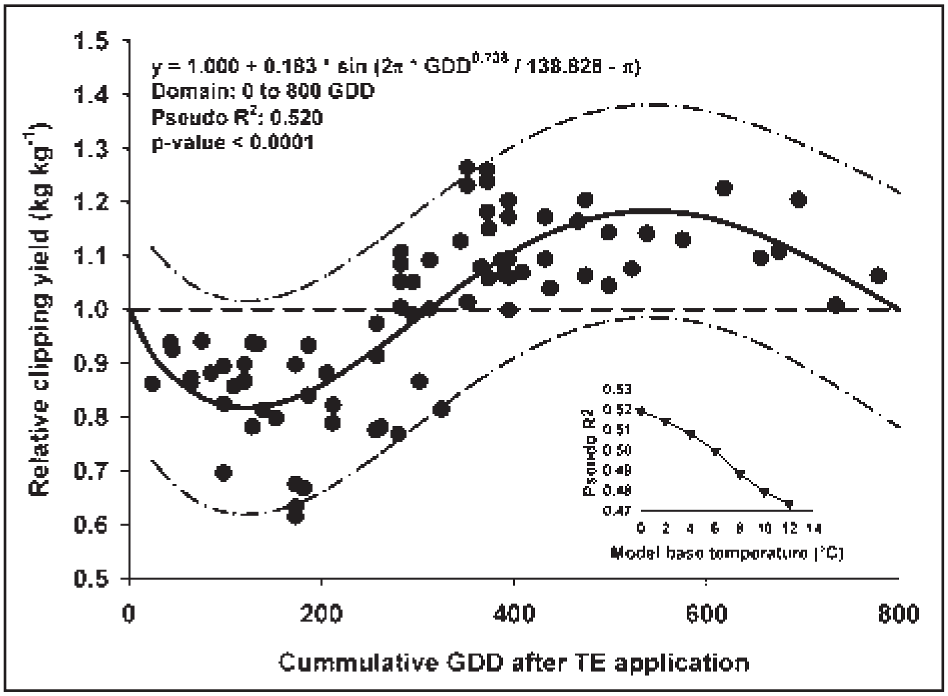

Figure 3. Growing degree-day models can predict the duration and magnitude of both the suppression and rebound phases. A base temperature of 0 degrees Celsius produced the best model results.

ing resistant or immune to the PGR. However, the reduced response was only observed during summer. Researchers also were observing reduced efficacy of trinexapac-ethyl during summer (Lickfelt et al., 2005; Beasley and Branham, 2007). Branham and Beasley (2005) at University of Illinois provided an explanation when they showed breakdown of trinexapac acid (the plant-active form of Primo® Maxx) and paclobutrazol increased as air temperature increased. This result led researchers to question the efficiency of calendar-based PGR scheduling and suggests that PGRs should be reapplied more frequently during warm summer months than during cooler months in spring and fall.

Growing degree-day (GDD) models are widely used to relate crop growth and development to air temperature in production agriculture. To calculate GDDs, the high and low air temperatures are averaged, subtracted from a base temperature where metabolism is minimal, and added to values from previous days. Researchers hypothesized that GDD models could also predict the duration of growth suppression and that there was an ideal GDD-based reapplication interval that sustained yearlong yield suppression regardless of air temperature.

To test the GDD reapplication interval theory, a field study was started on a creeping bentgrass putting green during 2008. The study was simple — Primo® Maxx (trinexapac-ethyl) was applied every 100, 200, 400, and 800 GDDs and every four weeks. Daily GDDs were calculated in Celsius with a base temperature of 0 degree Celsius, and the model was reset to 0 after Primo® Maxx was reapplied. Clippings were collected and weighed roughly five days each week, and the relative growth rate was related to cumulative GDDs following Primo® Maxx application. The goal of the research was to identify a GDD interval that sustained season-long suppression of clipping yield.

The research showed GDD models successfully predicted the duration of both the suppression and rebound growth phases following Primo® Maxx application (Fig. 3). The suppression phase occured 0 to 300 GDD after Primo® Maxx application, followed by the rebound phase from 300 to 800 GDD (Kreuser and Soldat, 2011). Relative yield suppression was mirrored during the rebound — 20 percent of the control. The 400 GDD, 800 GDD, and four-week reapplication intervals did not sustain the suppression phase (Fig 4). Both the 100 and 200 GDD intervals prevented the rebound phase. The GDD model was verified in 2009 and 2010 at two Primo® Maxx application rates — 5.5 or 11 fluid ounces/acre (0.125 or 0.250 fluid ounce/1,000 square feet). Again, the 200 GDD Primo® Maxx reapplication interval sustained clipping yield suppression during the growing season. Interestingly, the application rate did not affect the intensity or duration of the growth suppression phase (Kreuser and Soldat, 2011). This research clearly showed that Primo® Maxx needed to be applied more frequently to sustain

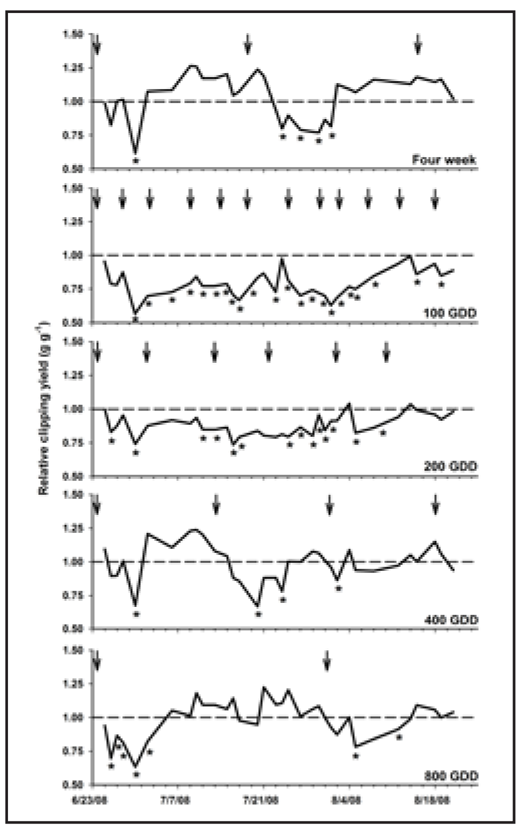

Figure 4. Trinexapac-ethyl was reapplied every 100, 200, 400, and 800 GDDs or every four weeks. The 100 and 200 GDD reapplication intervals maintained growth suppression, while the other intervals did not prevent the rebound phase from occurring.

yield suppression during warm periods and not at a higher rate.

Since the initial GDD studies, the 200 GDD reapplication interval for Primo® Maxx has proven to be effective in several northern states, from New York to Nebraska. Superintendents from around the world have started to use GDD models to schedule PGR applications on cool-season greens — annual bluegrass and creeping bentgrass greens respond similarly to PGR application intervals determined by the GDD model (Kreuser, 2014). Additionally, researchers have also developed GDD thresholds for other PGRs. The latest research shows GDDs also can predict growth phases of paclobutrazol (Trimmit® 2SC, Syngenta) (Kreuser et al., *in prep*). The estimated GDD threshold and peak growth suppression for Trimmit® 2SC were 350 GDD and 45 percent suppression at 11 fluid ounces/acre (0.25 fluid ounce/1,000 square feet) (Fig. 5). However, unlike Primo® Maxx, there is evidence of a rate effect with paclobutrazol. Higher application rates resulted in increased growth suppression for a longer period of time (Fig 5). More research will be conducted during the summer of 2015 to understand the rate effect of class B PGRs on putting green performance.

Mixing paclobutrazol and trinexapac-ethyl resulted in slightly more growth suppression but did not increase the duration of growth suppression on cool-season greens (Kreuser et al., *in prep*). There was some evidence that peak growth suppression occurred sooner when class A and class B PGRs were mixed together; however, GDD-based reapplication intervals make this a nonissue because the turfgrass never leaves the growth suppression phase. Additionally, increased growth suppression could be achieved with a higher rate of paclobutrazol. The ideal GDD reapplication interval for mixtures of class A and class B PGRs should be the reapplication interval of the class B PGR since it lasts longer in the plant.

Most PGR GDD studies have only been conducted on creeping bentgrass or mixed annual bluegrass/creeping bentgrass greens in northern states. Thus, the recommended GDD thresholds are only applicable to those types of greens. Other turf species under different management respond differently to PGRs. For example, McCullough et al. (2006 and 2007) have shown that bermudagrass greens are much more sensitive to PGRs than creeping bentgrass. Application of trinexapac-ethyl at 5.5 fluid ounces/acre (0.125 fluid ounce/1,000 square feet) or less suppressed Tifway bermudagrass growth by greater than 50 percent for a period of four weeks (McCullough et al.; 2006 and 2007). At higher rates of trinexapac-ethyl, significant phytotoxicity has been reported on bermudagrass (McCullough et al., 2006). As a result, many turfgrass managers with bermudagrass greens commonly apply trinexapac-ethyl at light rates — e.g., less than 2 fluid ounces/acre or 0.05 fluid ounce/1,000 square feet — weekly during the growing season.

Other turfgrass scientists are currently evaluating GDD models and reapplication thresholds for other turfgrass species. Dr. McCullough is currently developing models for warm-season grasses at the University of Georgia. Dr. McCullough is taking the GDD model a step further by combining air temperature and sunlight data to more accurately predict PGR performance. Also, researchers at the University of Minnesota are looking at GDD models for Kentucky bluegrass maintained as golf fairway and athletic field turf. To help track GDDs, an Excel spreadsheet is available at turf.unl.edu, and a web-based app also will be available in late spring 2015.

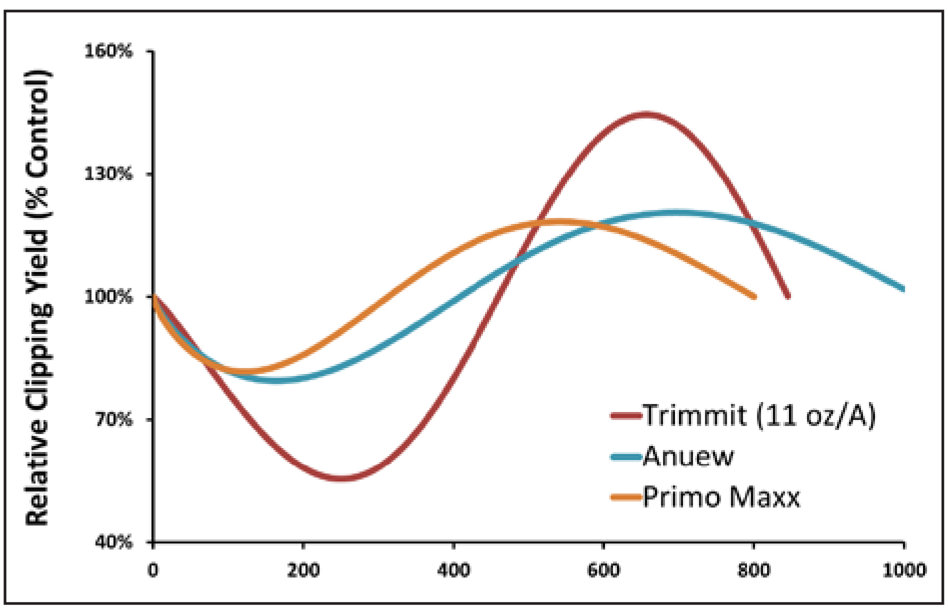

Figure 5. GDD models also predict growth suppression and rebound of paclobutrazol. Mixing paclobutrazol and trinexapac-ethyl resulted in slightly greater growth suppression but did not lengthen the duration of growth suppression.

BENEFITS OF CLIPPING YIELD SUPPRESSION IN TURF

On putting greens, most golf course superintendents use PGRs for reasons other than clipping yield reduction. The scientific literature is full of many examples of secondary benefits related to PGRs. For example, routine applications of trinexapac-ethyl increase turfgrass color and visual quality ratings (Ervin and Zhang, 2008). Gibberellin-inhibiting PGRs reduce leaf cell length, increase cell density, and increase chlorophyll concentration, which increases turfgrass color (Ervin and Koski, 2001; Stier and Rogers, 2001; Bunnell et al., 2005). Turf color and visual quality were greatest when PGRs were applied more frequently (Stier et al., 1999; Qian and Engelke, 1999). Trinexapac-ethyl also increases tiller density and leaf area index (Ervin and Koski, 1998; Beasley and Branham, 2007). Other PGR benefits include increased carbohydrate storage, improved stress tolerance, and reduced nitrogen fertilization requirements. The effects of gibberellin-inhibiting PGRs on the roots of both cool- and warm-season turfgrasses has been less conclusive (Ervin and Zhang, 2008).

These secondary benefits of PGRs arise during the suppression phase, which is why it's important to sustain season-long clipping yield reduction when using PGRs on turf. For example, total nonstructural carbohydrates (TNC) — the energy reserves of the plant that sustain growth and survival during darkness and when turf is under intense environmental stress — were observed to increase after turfgrass was treated with trinexapac-ethyl but then declined 4 to 16 weeks after application, closely mirroring the suppression and rebound growth phases (Han et al., 1998 and 2004). Similar phenomena occurred in hybrid bermudagrass (Waltz and Whitwell, 2005) and when TNC were measured during the rebound phase in tall fescue (Richie et al., 2001). Carbohydrate stores increase as clipping yield slows during the suppression phase, but growth enhancement during the rebound phase quickly depletes stored TNC.

Sustained clipping yield suppression also can reduce putting green nitrogen requirements (Kreuser and Soldat, 2012). Clippings are commonly removed from putting greens during mowing to improve playability. This can remove a significant amount of nitrogen, which needs to be replaced with fertilizer to sustain acceptable putting green performance and quality. Limiting growth with a PGR is one way to reduce nitrogen loss during mowing, but this only occurs when clipping yield is suppressed for the entire growing season. Researchers conducted an experiment on a creeping bentgrass putting green in Madison, Wis., from 2008 to 2010. The green was fertilized with 0.1, 0.2, or 0.4 pound nitrogen/1,000 square feet every two weeks. In the first year the plots were treated with trinexapac-ethyl (Primo® Maxx) every three weeks or not treated with a PGR. At the end of the season plots treated with trinexapac-ethyl had the same nitrogen response/requirements as non-PGR-treated plots. Clipping yield data showed that yield suppression was not sustained over the entire season, and nitrogen saved during the suppression phase was lost during the rebound phase. The following two years, trinexapac-ethyl was applied every 200 GDDs. On average, trinexapac-ethyl conservatively reduced nitrogen requirements by 20 to 40 percent, because trinexapac-ethyl increased turf color and limited nitrogen removal during mowing. There were several rating dates when plots treated with 0.2 pound nitrogen/1,000 square feet and trinexapac-ethyl had quality similar to plots treated with 0.4 pound nitrogen/1,000 square feet (Fig. 6), and clipping yield was similar to plots that were fertilized with 0.1 pound nitrogen/1,000 square feet without trinexapac-ethyl. A word of caution however: Greens that have received very frequent PGR applications in the past likely have accounted for the change in nitrogen requirements. A further reduction in nitrogen may lead to a decline in turfgrass quality.

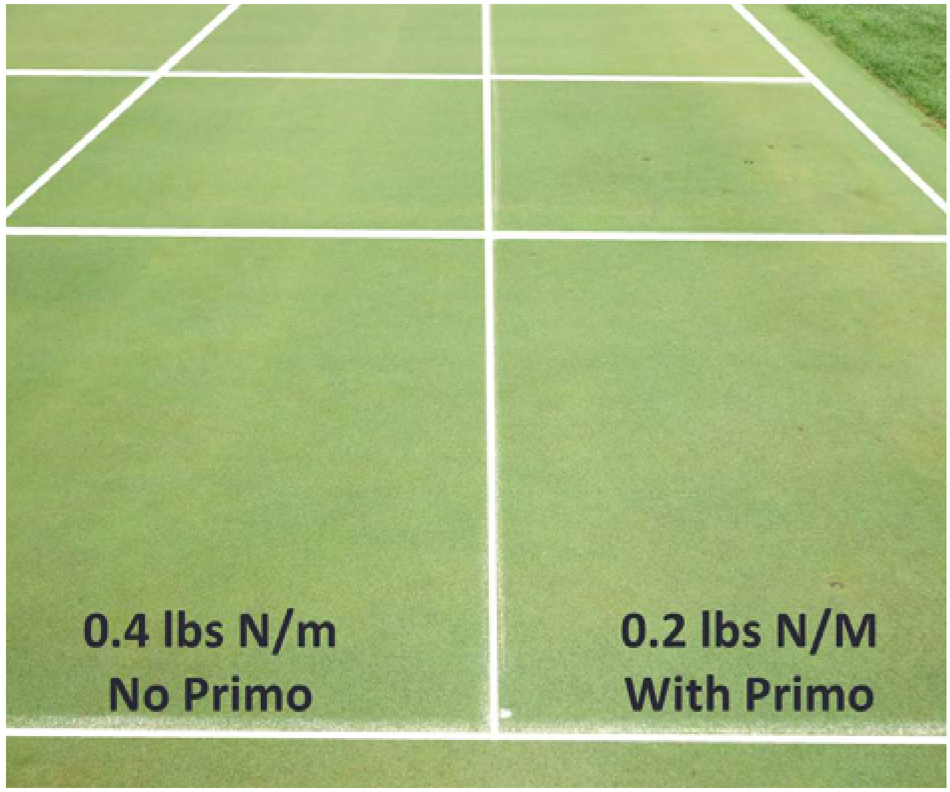

Figure 6. Turf on the right was fertilized with 0.2 pound nitrogen/1,000 square feet and was treated with trinexapac-ethyl every 200 GDDs. Turf on the left was fertilized with 0.4 pound nitrogen/1,000 square feet but did not receive trinexapac-ethyl. These treatments had similar turfgrass quality on a majority of rating days during 2009 and 2010.

PGRS AND BALL-ROLL DISTANCE

Another important reason PGRs are applied to putting greens is to increase green speed or ball-roll distance. The rationale is PGRs slow leaf growth, which increases green speed, and there is evidence that PGRs increase ball-roll distance on bermudagrass putting greens. Recently, McCarty et al. (2011) found that flurprimidol and trinexapac-ethyl increased ball-roll distance on TifEagle bermudagrass greens by 8 and 2 inches in the morning and 10 and 4 inches when measured in the afternoon, respectively. McCullough et al. (2007) also showed ball-roll distance increased 10 inches on TifEagle bermudagrass when trinexapac-ethyl was applied weekly (1.8 fluid ounces/acre), every two weeks (3.7 fluid ounces/acre), or every three weeks (5.5 fluid ounces/acre).

However, results have not been as clear for other grass species. Trinexapac-ethyl applied weekly to Diamond zoysiagrass greens (1.8 fluid ounces/

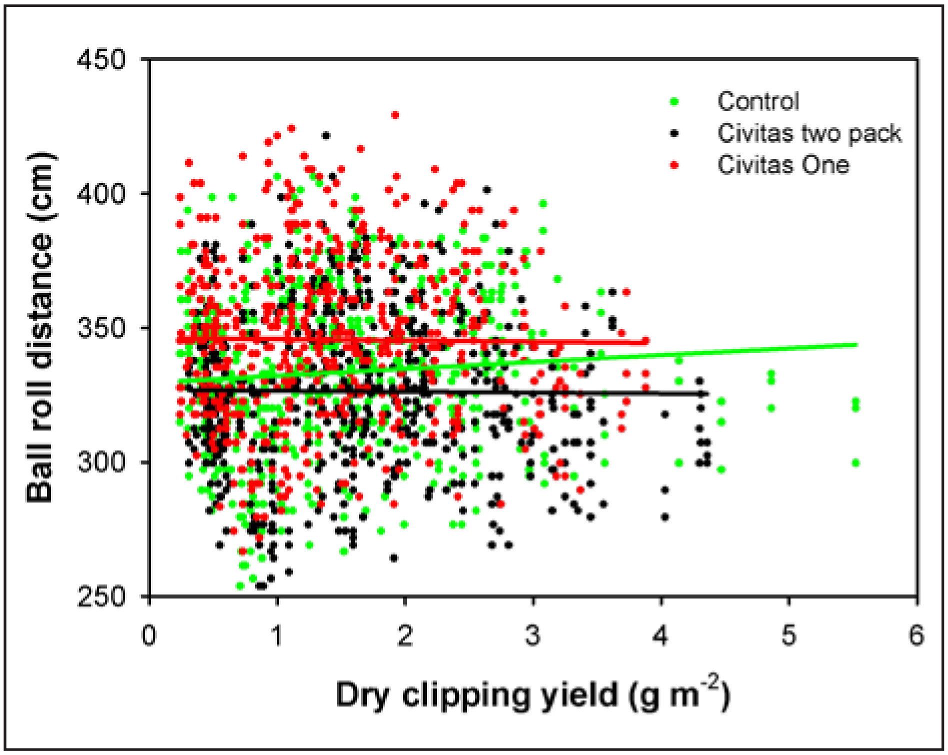

Figure 7. Clipping yield was a very poor predictor of ball-roll distance.

acre) slightly increased ball-roll distance on some occasions, but it reduced ball-roll distance or had no effect on other rating dates (Menchyk et al., 2014). The story is similar for cool-season putting greens. Early research indicated that trinexapac-ethyl does not affect ball-roll distance to a level detectable by golfers, i.e., plus or minus 6 inches (Fagerness et al., 2000; McCullough et al., 2005; Karcher et al., 2006). Reapplication of PGRs with GDD intervals also failed to increase ball-roll distance by a practically significant amount (McDonald et al., 2013; Kreuser, 2014). Even class B PGRs, which produce more relative growth suppression than trinexapac-ethyl, only increased ball-roll distance 0 to 5 inches (Kreuser and Rossi, *in prep*). Further analysis of the data showed there wasn't a relationship between ball-roll distance and clipping yield (Fig. 7) (Kreuser, 2014). It's likely other factors, such as leaf firmness/succulence, quality or cut, and surface micro-topography, have a greater effect on ball roll than clipping yield. Fagerness et al. (2000) and Kreuser (2014) both showed that ball-roll distance declined as putting green visual quality declined. These results suggest golf course superintendents strive to maintain good quality turf to maximize ball roll.

ANNUAL BLUEGRASS CONTROL WITH PGRS

Plant growth regulators also are used to control annual bluegrass proliferation in creeping bentgrass greens. Class B PGRs typically provide better annual bluegrass control than trinexapac-ethyl. There are numerous reports of annual bluegrass control with paclobutrazol and flurprimidol on creeping bentgrass fairways (Bigelow et al., 2007; Isgriss et al. 1999 a and b; Johnson and Murphy, 1995 and 1996; McCullough et al., 2005; Wooley et al., 2003). Class B PGR applications never completely eradicate annual bluegrass, but they can slow annual bluegrass invasion. In contrast, trinexapac-ethyl has a limited effect controlling annual bluegrass in creeping bentgrass fairways (Bigelow et al., 2007; McCullough et al., 2005; Rossi, 2001). New research from Reicher et al. (2015) revealed similar annual bluegrass control on creeping bentgrass greens in Indiana, Michigan, and Nebraska over three years. Frequent applications of paclobutrazol (Trimmit® 2SC, Syngenta) provided the greatest amount of annual bluegrass control, followed by flurprimidol (Cutless® MEC, SePRO), flurprimidol plus trinexapac-ethyl (Legacy®, SePRO), and finally trinexapac-ethyl, which was the same as the control (Fig. 8).

It's believed by many in the golf industry that "Primo® equals *Poa*."

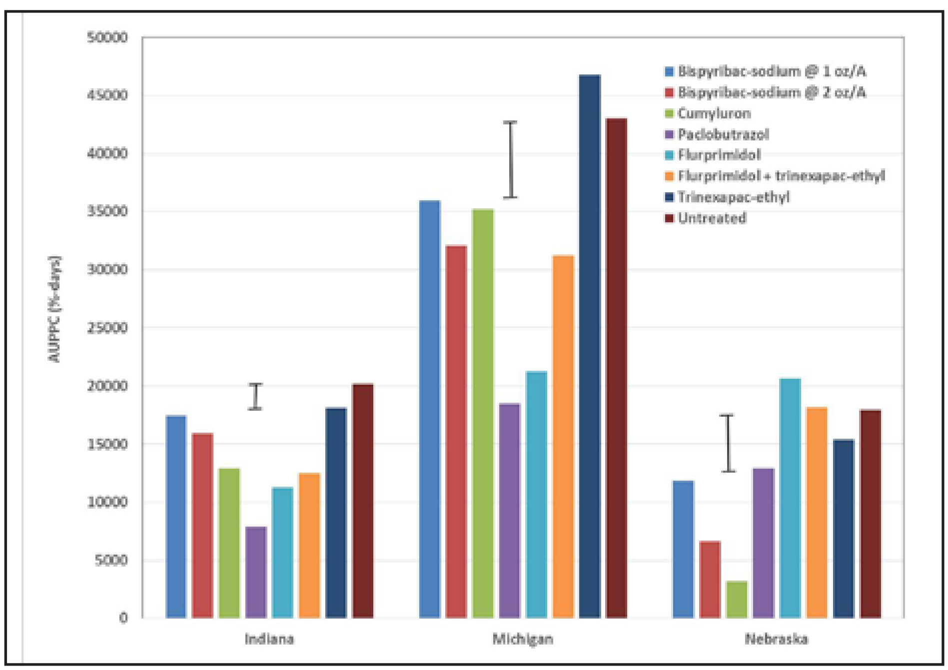

Figure 8. Area under the Poa *progress curve from creeping bentgrass greens treated with different growth regulators for three years. Adapted from Reicher et al., 2015.*

While the research doesn't support this idea, the rationale is that trinexapac-ethyl makes annual bluegrass healthier and more likely to survive summer stress. An alternative hypothesis would be that trinexapac-ethyl makes annual bluegrass more noticeable. To examine these hypotheses, a mixed creeping bentgrass/annual bluegrass green was treated with three different rates of Primo® Maxx (0.125, 0.250, 0.500 fluid ounce/1,000 square feet) every 200 GDDs. After two months of treatments, attendees at the 2009 University of Wisconsin Turf Field Day were asked to visually estimate the percentage of the putting green surface covered by annual bluegrass. The following day, the actual percentage of annual bluegrass was measured with a grid containing over 700 crosses. Turf treated with Primo® Maxx every 200 GDDs had less annual bluegrass than the non-treated control plots (Fig. 9). However, visual estimates indicated that the 0.125 and 0.500 fluid ounce Primo® Maxx/1,000 square feet plots had more annual bluegrass than the control. Raters only saw half of the actual amount of annual bluegrass in the non-treated plots, but they fairly accurately estimated the percentage of annual bluegrass in Primo® Maxx treated plots (Fig. 9). The application of Primo® Maxx increased the contrast between the annual bluegrass and the creeping bentgrass. Leaf density increased, the leaves segregated, and the bentgrass had a darker blue-green color when treated with Primo® Maxx. As a result, our skilled turfgrass professionals accurately estimated the annual bluegrass in plots treated with Primo® Maxx.

PGRS AND ETIOLATION

Bacterial etiolation has become a hot topic in the turf industry. Affected turfgrass typically exhibits rapid leaf elongation and leaf chlorosis. This disease is caused by *Acidovorax avenae* subsp. *avenae* and *Xanthomonas translucens* (Giordano et al., 2012; Roberts et al., 2014b). While symptoms of bacterial etiolation are partially triggered by stress, trinexapac-ethyl has been shown to increase severity of leaf etiolation. Roberts et al. (2013 and 2014a) found that creeping bentgrass previously inoculated with *Acidovorax avenae* subsp. *avenae* had more leaf etiolation when treated with trinexapac-ethyl. Interestingly, turf treated with trinexapac-ethyl also had the greatest visual turf quality. Etiolation symptoms were worse when trinexapac-ethyl was applied every 7 days compared to every 14 days. Paclobutrazol and flurprimidol did not affect disease severity relative to the control (Roberts et al. 2014a). The scientific community is still trying to understand why trinexapac-ethyl intensifies etiolation. Until we know more, researchers recommended using a class B PGR during severe outbreaks of bacterial etiolation.

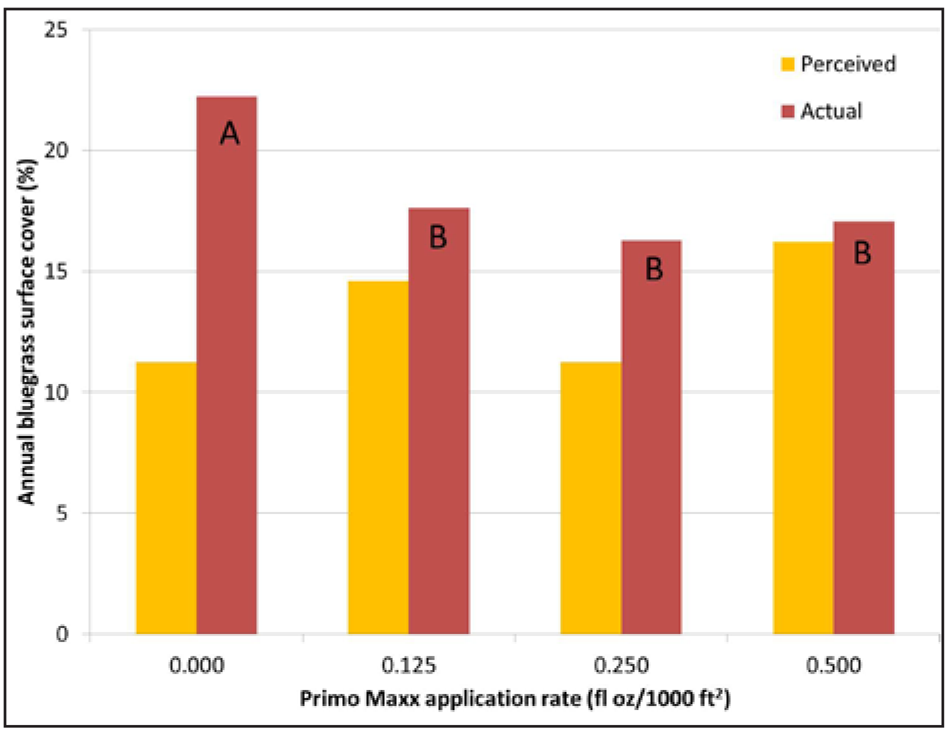

Figure 9. Professional turfgrass managers were asked to visually estimate the amount of annual bluegrass cover on a putting green treated with various rates of Primo® Maxx every 200 GDDs. Annual bluegrass composition was then measured with grid counts. At higher Primo® Maxx rates, there was more contrast between annual bluegrass and creeping bentgrass. This allowed raters to accurately estimate the amount of annual bluegrass on the putting green.

SUMMARY

Gibberellic acid inhibiting PGRs have proven to be an important tool in putting green management. In addition to reducing clipping yield, they can increase turf color and tiller density, improve turf quality, reduce nitrogen requirements, improve stress tolerance, and suppress annual bluegrass encroachment. To maximize PGR potential, golf course superintendents need to strive to sustain season-long yield suppression. Unfortunately, visually estimating PGR performance in the field is next to impossible. This makes it challenging to know when to reapply PGRs. Growing degree-day models offer a simple and effective way to estimate PGR performance. These models move PGR scheduling away from inefficient calendar-based intervals and toward intervals based on plant metabolism. Growing degree-day reapplication thresholds provide an easy way to sustain yield suppression, avoid the rebound phase, and maximize secondary benefits.

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