PLANT GROWTH REGULATORS ON GOLF COURSES

USGA Green Section Collection

This USGA Green Section Collection – assembled to supplement the April 3, 2015 issue of the *Green Section Record* (vol. 53 issue 7) – provides useful resources about the use of plant growth regulators on turfgrass. The information contained in this collection is not all–inclusive but is intended to offer additional information about plant growth regulators, why they are used, and how they can benefit turfgrass and the game of golf.

April 3, 2015

For the good of the game®

Introduction

In 1920, E.J. Marshall, a Toledo, Ohio attorney and then Green Committee chairman for the Inverness Club, was in charge of course preparations for the U.S. Open Championship. Marshall sought, but could not find, impartial and authoritative agronomic information. His efforts led him to the USGA and the United States Department of Agriculture. The two organizations agreed to collaborate in the development of scientific information relating to golf course turf. Thus, on November 30, 1920, the Executive Committee of the United States Golf Association formally created the USGA Green Section.

This not–for–profit agency, free from commercial connections, was a pioneer and remains today a chief authority in turfgrass management for golf. The USGA Green Section is directly involved in every phase of golf course maintenance and management from the control of diseases, insects, and weeds to the breeding and release of improved strains of turfgrass. Furthermore, the USGA supports the largest, private turfgrass and environmental research effort in the history of golf focusing on resource conservation, cultural practices, soils, fertilizers, irrigation, and other aspects of turfgrass management.

Since 1921, the USGA Green Section has published information on the proper maintenance and upkeep of golf courses. Published under various titles, the *Green Section Record* magazine debuted in May 1963. In July 2010, the print publication changed to a bimonthly digital magazine offering the latest information on golf course management, turfgrass culture, environmental issues, research and economic sustainability.

By supporting research and offering sound, experienced, unbiased agronomic advice about the scientific and practical aspects of golf course turf management, the USGA *Green Section Record* provides ever greater value and better golf turf to the golf facilities and course officials it services.

Cover photo: Winged Foot Golf Club in Mamaroneck, N.Y. (©USGA/John Mummert)

Photo: 2011 U.S. Open at Congressional Country Club in Bethesda, Md. (©USGA/Michael Cohen

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Plant growth regulators affect more than growth, they can affect the way a golf course looks, plays and is maintained.

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.

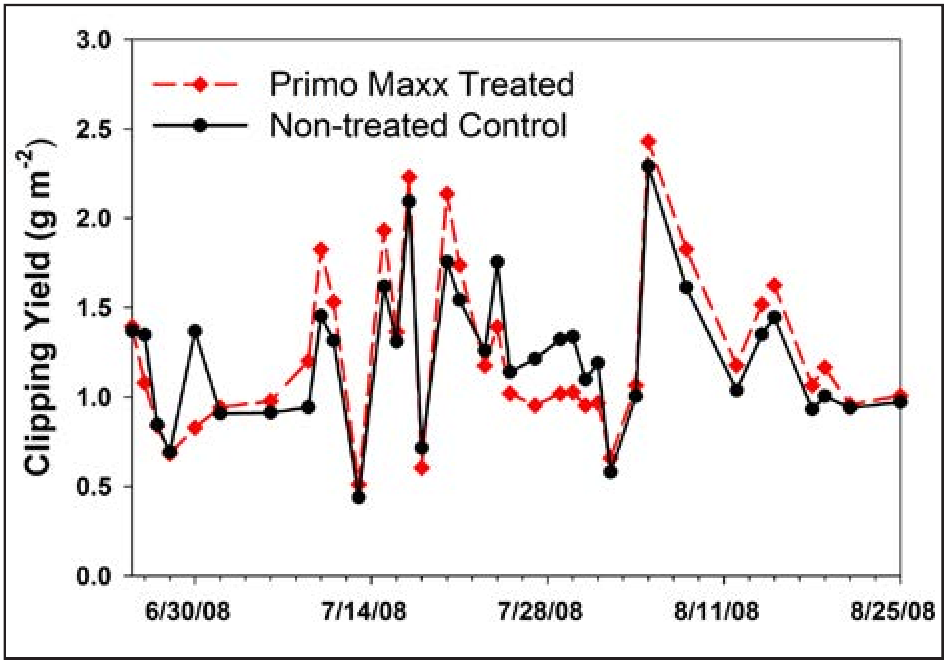

Figure 1. Fluctuations in actual clipping yield of a creeping bentgrass green. The red line represents plots treated with trinexapac-ethyl and the black represents the control. Day-to-day fluctuations in clipping yield were more extreme than changes resulting from PGR application.

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.

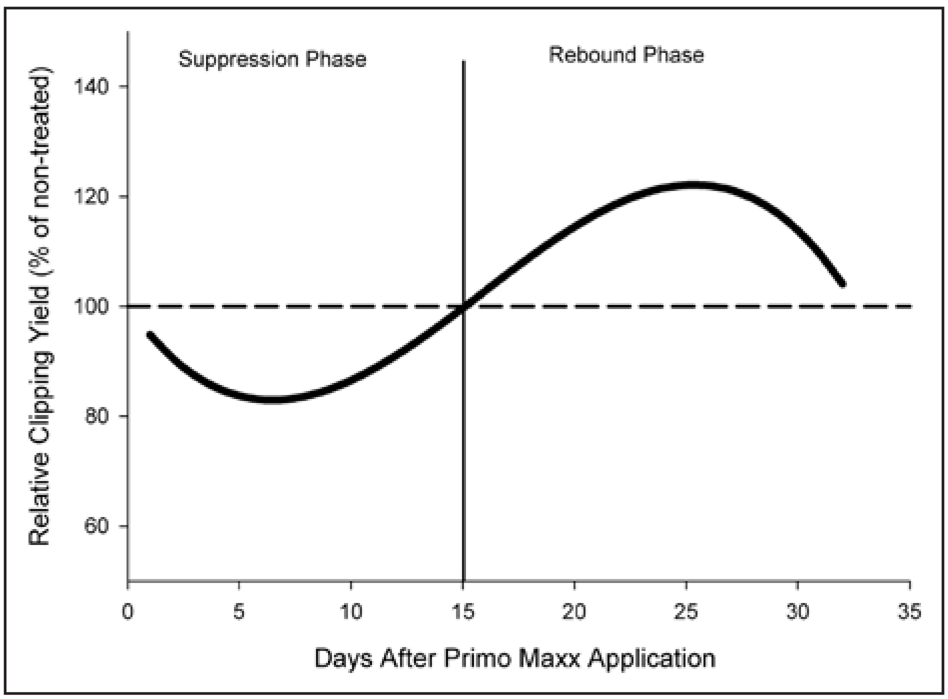

Figure 2. Gibberellic acid inhibitors affect growth in two phases. The first phase is growth suppression. The second phase is a rebound phase where clipping yield is greater than untreated turfgrass.

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-

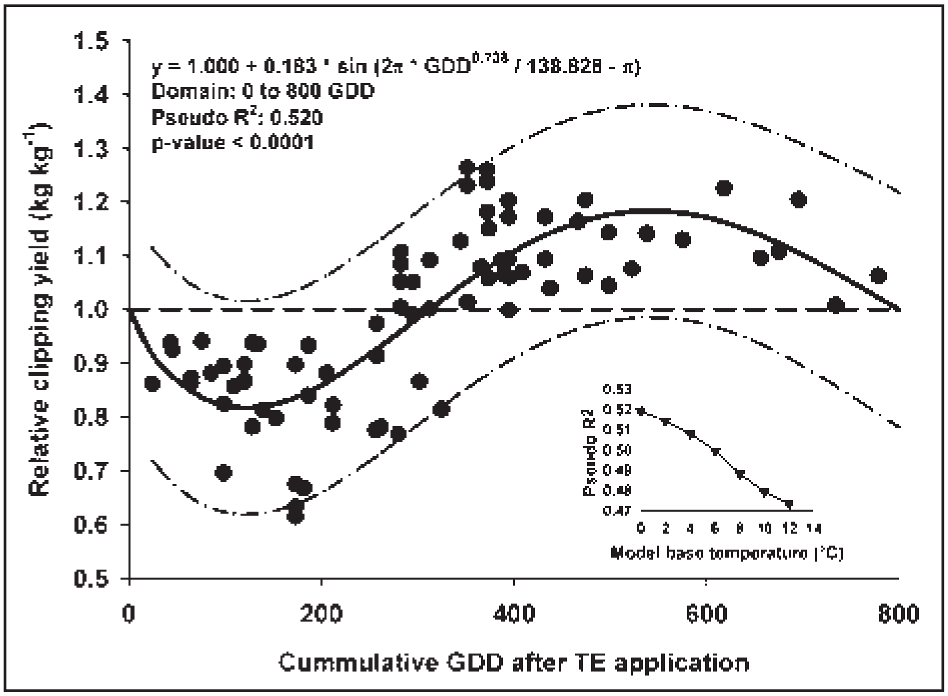

Figure 3. Growing degree-day models can predict the duration and magnitude of both the suppression and rebound phases. A base temperature of 0 degrees Celsius produced the best model results.

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

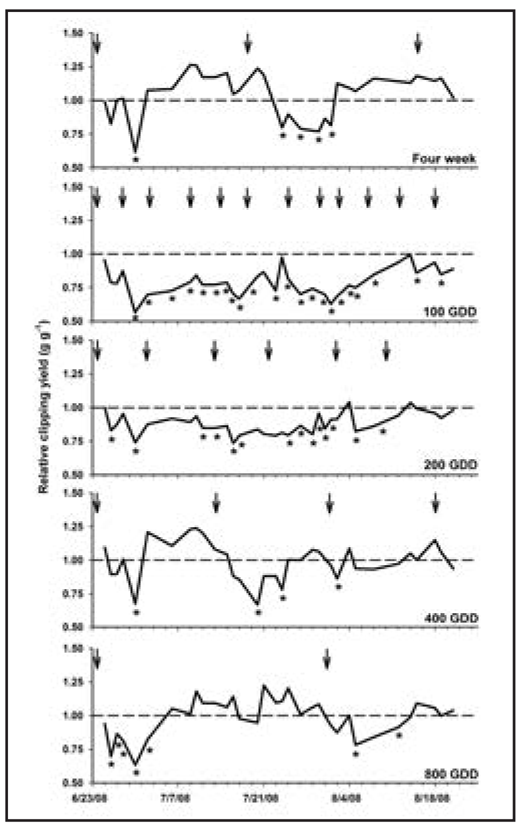

Figure 4. Trinexapac-ethyl was reapplied every 100, 200, 400, and 800 GDDs or every four weeks. The 100 and 200 GDD reapplication intervals maintained growth suppression, while the other intervals did not prevent the rebound phase from occurring.

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.

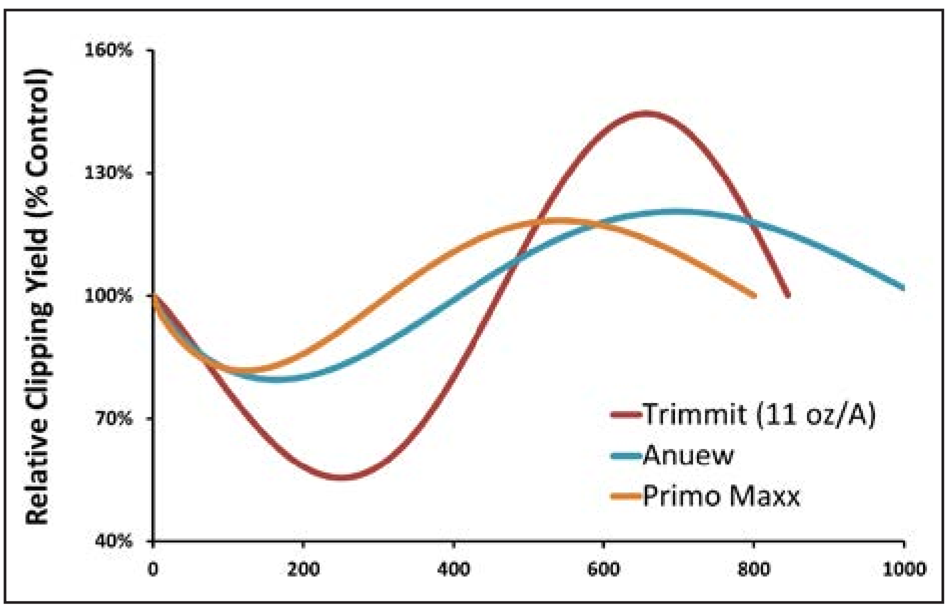

Figure 5. GDD models also predict growth suppression and rebound of paclobutrazol. Mixing paclobutrazol and trinexapac-ethyl resulted in slightly greater growth suppression but did not lengthen the duration of growth suppression.

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/

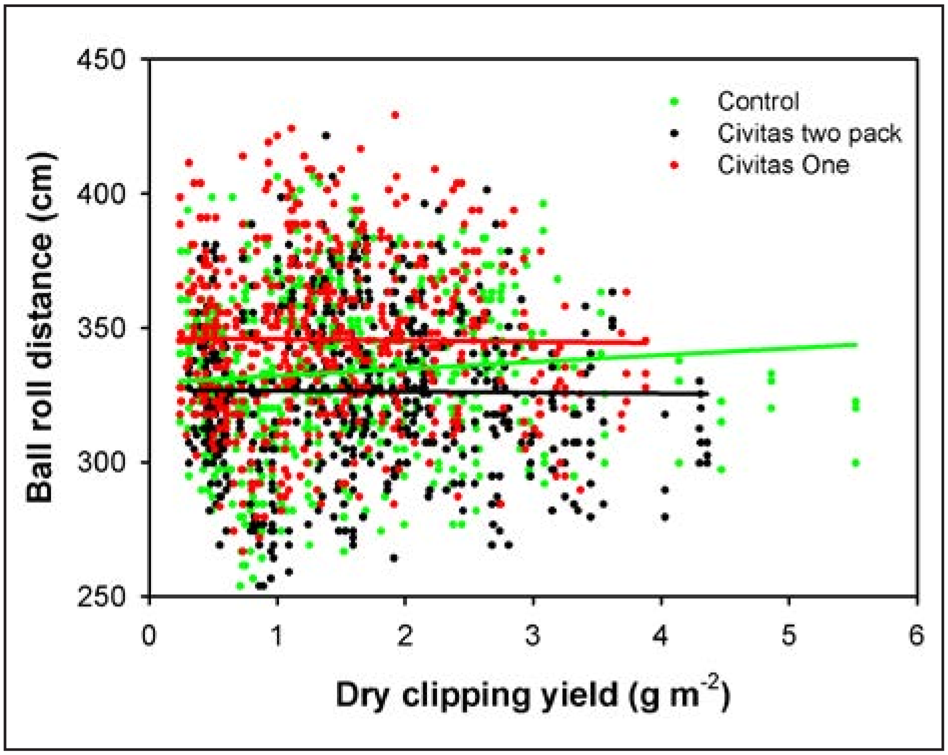

Figure 7. Clipping yield was a very poor predictor of ball-roll distance.

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*."

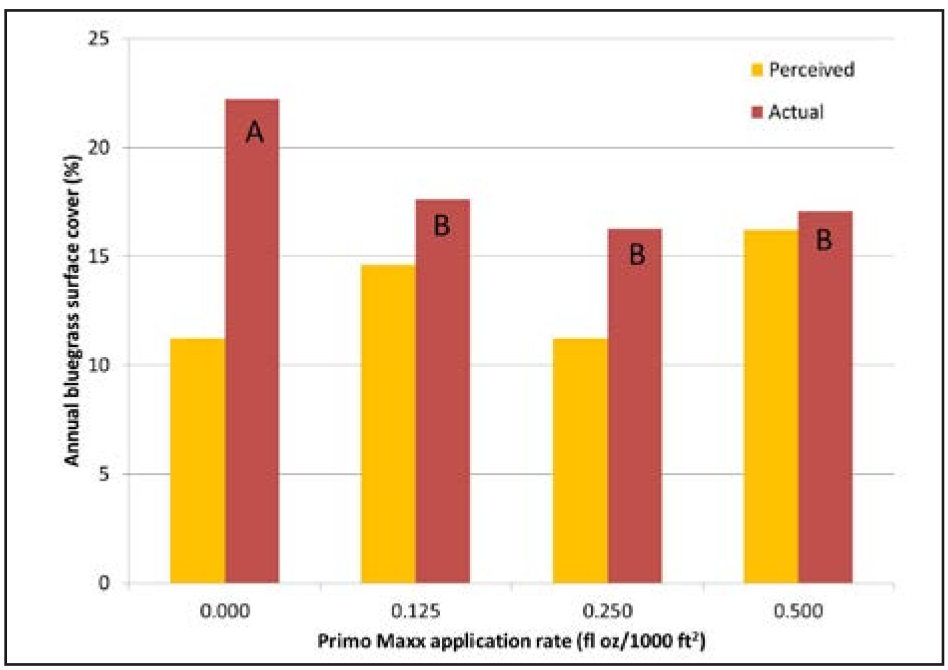

Figure 8. Area under the Poa *progress curve from creeping bentgrass greens treated with different growth regulators for three years. Adapted from Reicher et al., 2015.*

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.

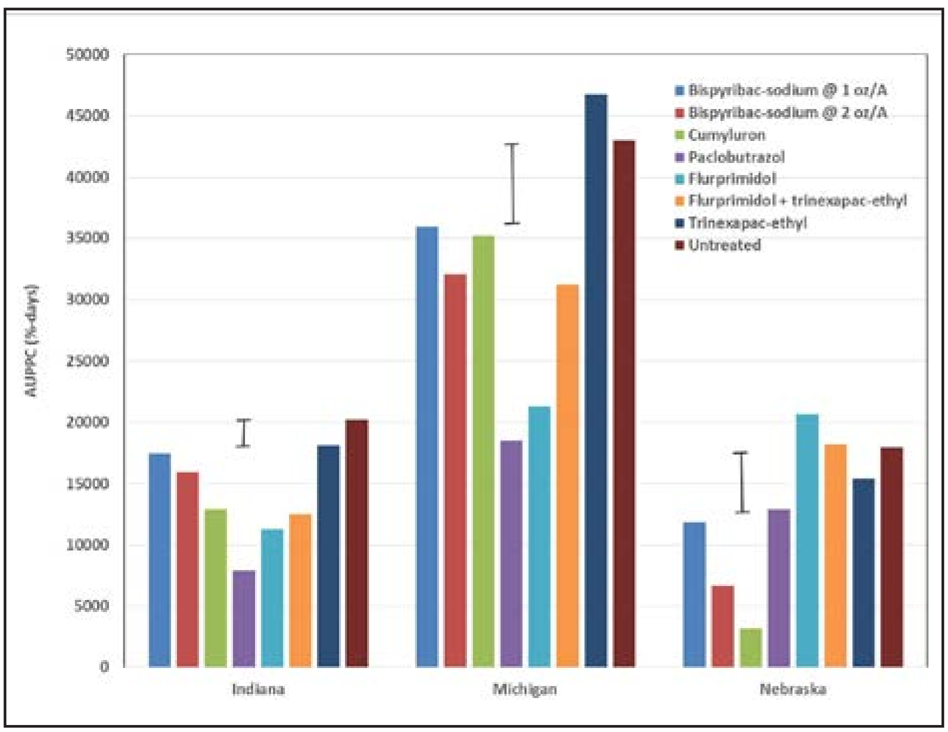

Figure 9. Professional turfgrass managers were asked to visually estimate the amount of annual bluegrass cover on a putting green treated with various rates of Primo® Maxx every 200 GDDs. Annual bluegrass composition was then measured with grid counts. At higher Primo® Maxx rates, there was more contrast 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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Plant Growth Regulators in Bentgrass Turf Areas

Thoughts and trends in the use of a valuable management tool.

BY CALE A. BIGELOW

Reductions in clipping yield are a major advantage for many practical reasons.

The focus of this article is plant growth regulators (PGRs) and how they can be used as a management tool for golf turf. My goal is to offer current insights, share some personal thoughts, and offer cautions and suggestions to maximize the effectiveness of their use.

Ethephon (Proxy), flurprimidol (Cutless), mefluidide (Embark T & O), paclobutrazol (Trimmit), and trinexapac-ethyl (Primo MAXX) are the primary growth regulator active ingredients currently used on fine, cool-season turf. Most golf course managers use or have used these products at one time or another. One main reason to use a PGR is to suppress vertical leaf growth. Aside from less mowing and reduced scalping potential, regularly applied PGRs provide smoother and more uniform playing surfaces, but there are many other beneficial effects. In terms of increased lateral spreading, the effects are rather variable. Rooting effects are always a concern, but for PGRs, negative effects on rooting are extremely rare. In fact, there are actually some positive rooting effects from top-growth suppression, but do not expect huge differences. There are many other possible benefits, such as seedhead suppression (mefluidide and ethephon are most effective), higher shoot density, improved color, shade tolerance, reduced water consumption, and dollar spot suppression (flurprimidol and paclobutrazol are most effective for this purpose, with paclobutrazol offering slightly more suppression).

TURFGRASS SAFETY

A major concern in past decades with PGRs was discoloration or injury. The products labeled for repeated seasonal application to fine turf, flurprimidol, paclobutrazol, and trinexapac-ethyl, are all safe to creeping bentgrass when applied correctly and according to label recommendations. Even with application rate issues or sprayer overlap at higher label rates, there is little chance the turf will actually die. The turf may appear injured (e.g., bronzing or leaf purpling, severely puckered tillers, etc.), and stressed turf may decline further, but, in my experience, it eventually recovers. This fact, however, might not hold true for mefluidide, which has a different mode of action than the aforementioned PGRs that suppress gibberellic acid synthesis.

By contrast, other species like Kentucky bluegrass may be discolored or injured by PGRs. This is important because many golf courses have Kentucky bluegrass roughs or green/tee surrounds, and paclobutrazol or mefluidide applications can cause subtle injury. These symptoms are less rare where flurprimidol or trinexapac-ethyl are used. One additional caution with PGR use: when using a DMI (demethylation inhibitor) fungicide in conjunction with a PGR program, understand that the combination of these materials may further regulate the turf.

Another suggestion when using any of these PGRs is to tank-mix a small amount of soluble nitrogen, such as urea and/or a liquid chelated iron source. This will minimize discoloration and continue to stimulate growth/density without excess clipping production.

NEW PRODUCTS AND FORMULATIONS?

At present, it does not seem that there are any new PGRs coming to the

Annual bluegrass seedhead production is a major issue in terms of playability on putting greens, and certain PGRs and combinations can be very effective in reducing their production.

marketplace. Much like the fungicide and herbicide markets, manufacturers are looking for value-added combinations of existing molecules. Currently there is one pre-mix combination product (Legacy) on the market that combines flurprimidol and trinexapac-ethyl in a liquid formulation.

The potential benefit of this combination is that it is absorbed both through the foliage and via the roots. The foliar regulation from trinexapac-ethyl happens more quickly (hours), whereas the root-absorbed flurprimidol regulation happens more slowly but offers a more steady supply of the PGR from the rootzone. This should translate to less rebound growth effect as the PGR wears off. In addition, a new liquid formulation of flurprimidol (Cutless MEC) has been introduced, allowing turf managers to more easily adjust application rates compared to the powder formulation, especially for green and tee use.

APPLICATION RATES AND TIMING

Temperature matters! When PGRs were first introduced, the goal often was to simply suppress the major cool-season turfgrass growth peaks and clipping production. Generally, summer applications were avoided. Products were applied only a few times at higher label rates, and the expected duration of regulation was 4-6 weeks. Now, many managers use PGRs throughout the entire growing season with various rate strategies (e.g., higher spring and fall rates and lower in summer, or lower early spring and tapering to increasing rates during peak spring growth plus lower in summer, or constant rates throughout the year). The goal is to provide additional, and more consistent, regulation. Superintendents have tried many options and there appears to be no single correct program.

There also is the question of what is the "best" application interval? Several researchers have explored this, and the important thing to understand is that temperature matters. It affects growth rate, PGR metabolism, and more. Drs. Jeff Beasley and Bruce Branham, University of Illinois, studied the persistence of paclobutrazol and trinexapac-ethyl inside the plant and found that as temperature increased, the amount of PGR in the leaf tissue decreased, and the half-life or persistence of paclobutrazol was much greater than for trinexepac-ethyl (Beasley and Branham, 2005). This means that the root-absorbed PGR, paclobutrazol, has longer persistence and likely provides more uniform regulation over time. Since flurprimidol is chemically so close to paclobutrazol, I would expect a similar response.

Bill Kreuser and Dr. Doug Soldat at University of Wisconsin attempted to identify a specific growing degree day (GDD) model for optimum trinexapac-ethyl application frequency (Kreuser and Soldat, 2011). They reported that compared to a standard calendar-based application schedule, trinexapac-ethyl at 6 fl. oz. per acre should be applied every 200 GDD for consistent bentgrass regulation. The take-home message is that as the temperatures get warmer you may need to to tighten the intervals to achieve consistency. The last thing you want is PGR-regulated turf to rebound with rapid growth just prior to that important summer tournament or event. In practical terms, monitor your daily clipping production and watch the daily high and low temperatures. This is especially true during long days and warm temperatures in summer.

SUMMER PGR USE FREQUENTLY ASKED QUESTIONS

Should I continue my program during stressful conditions when stand density declines, or should I stop? Honestly, nobody really knows what is best, and solid arguments can be made to continue applications or stop. My bias is that less mower injury is probably better for the turf during late-summer stress. In recovery mode you are lightly feeding soluble nutrients and these, in turn, hopefully are pushing growth. If your turf is still under regulation, there is an option of alternating daily mowing and rolling (lightweight rolling only) for surface smoothness, which is more appealing than a leggy, succulent, slow putting surface. Another consideration is the potentially rapid regrowth process as the PGR wears off. This growth could be carbohydrate intensive and exhaustive at a time when the plant is physiologically impaired. Thus, I generally recommend staying the course for a few more applications until summer temperatures moderate. I feel the benefits of fine turf PGRs far outweigh the potential risk.

How do PGRs affect interseeding? This is another gray area. We do know, however that paclobutrazol, when applied two weeks after seedling emergence, can negatively affect establishment in fairway-height turf (Kaminski et al., 2004). The effect from other PGRs is less clear. One line of logic would be that if you have a thin green, you should stay on the PGR program as these products retard vertical growth and you might be able to again reduce mechanical stresses, rolling instead of mowing for greater seedling survival. But the effects of any chemical on young seedlings is always variable.

What about the interaction between PGRs and the mystery decline syndrome/disease? There have been recent discussions among the academic community regarding the potential role of PGRs in the poorly understood summer decline phenomenon syndrome (a.k.a. bacterial wilt/etiolation, mad-tiller, etiolated tiller, etc.), when individual leaves become chlorotic (yellow to almost white in some circumstances) and dramatically elongate almost overnight. The answer is, honestly, we just don't know. I can only speak from my personal observations of side-by-side, replicated research plots of bentgrass and mixed bentgrass/annual bluegrass turf with regulated turf and non-regulated turf. I have yet to see any clear differences; both treated and non-treated are affected. My sense is that there are environmental factors, cultivars, management practices, nutritional inputs, pathogens, and more all interacting.

Poa annua is suppressed differently with some PGRs. Regular application (every 14-21 days during the growing season) of one of the root-absorbed PGRs (i.e., paclobutrazol or flurprimidol) will suppress and can reduce annual bluegrass populations, often substantially (McCullough et al., 2005; Bigelow et al., 2007; Baldwin and Brede, 2011). In my research program we documented rather dramatic *Poa annua* reductions in established bentgrass/annual bluegrass research fairways/

Over regulation can result in turfgrass injury and usually is more damaging to Poa annua *than to creeping bentgrass. The* Poa annua *in this example is experiencing much more severe regulation than the adjacent bentgrass.*

greens. In this study, conducted in West Lafayette, Ind., the effects of flurprimidol (50W formulation) applied every 28 days over two consecutive years combined with and without trinexapac-ethyl to reduce annual bluegrass populations in fairway height creeping bentgrass were studied.

Applications were begun in mid-May and made monthly from May through October for two consecutive years to a recently established L-93 creeping bentgrass stand containing approximately 30% annual bluegrass that had established from an existing soil-seedbank. The most effective treatments were flurprimidol Cutless 50W alone at 16 oz/A or Cutless 50W flurprimidol + trinexapac-ethyl PrimoMaxx at 16 + 6 oz/A (Table 1). These results are encouraging and demonstrate that even with initial annual bluegrass populations of 30%, monthly root-absorbed PGR applications throughout the growing season can effectively reduce populations to more tolerable (less than 10%) levels. Of course, it is implied that these products work best when combined with sound cultural practices, such as adequate fertility, a reasonable mowing height, and proper compaction and thatch management.

A few other notes: Should I alter rates? My bias is to keep it simple. A single rate throughout the season is often as effective as varying the rate, with the added benefit of less room for applicator mixing errors. Second, take the applications into mid-autumn, if you can, to suppress annual bluegrass seedlings at the time when the majority

Table 1
Effect of monthly applications of flurprimidol (Cutless 50W) with and without trinexapac-ethyl (PrimoMaxx) on annual bluegrass reductions in a creeping bentgrass research fairway

		Percent change in annual bluegrass from initial[y]	
PGR	oz/A	Nov. Year 1	May 2 Years Later
Cutless 50W	8	- 39 a[z]	- 79 ab
Cutless 50W	16	- 24 ab	-75 abc
Cutless + Primo Maxx	4 + 6	- 28 a	- 38 d
Cutless + Primo Maxx	8 + 6	- 19 ab	-52 bcd
Cutless + Primo Maxx	16 + 6	- 36 a	- 87 a
Primo Maxx	12	+ 11 b	- 4 e
Untreated	—	+ 13.0 b	-44 cd

[y] Percentage annual bluegrass reductions were calculated based on initial populations recorded prior to growth regulator treatment.

[z] Means in the same column followed by the same letter are not significantly different according to Fisher's protected LSD t-test (p=0.05).

of them emerge throughout much of the cool-humid region (Kaminski and Dernoeden, 2007).

THE DISCLAIMER AND THE "FINE PRINT"

Annual bluegrass populations are highly variable. What works on one turf area or on one golf course can very easily not work down the street. The true annual biotypes seem more sensitive to these PGR programs than the more established perennial biotypes. Also, underestimating annual bluegrass populations can result in thin areas or, worse yet, noticeable voids in the turf canopy and golfer frustration if they are unaware of the long-term goals with the PGR program. Also, there may be some periodic and unpredictable discoloration (mild leaf bronzing/purpling) due to environmental conditions following application (mostly early spring or autumn with cold nights).

FUTURE RESEARCH

There is still much to learn about PGR use. In my research program we are focusing on understanding use patterns and improved efficacy. Questions such as the integrated effect of nitrogen sources, nutrition programs, and plant health supplements (a.k.a. biostimulants), soil water content issues, and if PGRs may help reduce water use and improve surface conditioning, are things we are evaluating. Stay tuned for more information.

In summary, I see PGRs as a vital tool for managing bentgrass on golf courses. There are many benefits beyond general vertical growth suppression, most notably annual bluegrass suppression. This is a tremendous benefit for bentgrass managers because bentgrass is more reliable during stressful summers than annual bluegrass. Long-term success, however, is somewhat like regularly taking medication for a chronic problem. The bottom line is they do work, but if you stop, results are uncertain and annual bluegrass will likely return.

Extended periods of wet weather can produce excess growth, and playability can suffer terribly if the turf is too wet to mow for a few days. PGRs are a major aid in reducing growth under these conditions, and this can translate to better playability and fewer scalping problems.

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Creative Uses for Plant Growth Regulators

They offer more advantages than growth reduction.

by NICK CHRISTIANS, Ph.D.

MY POSITION as a university educator has led to many opportunities over the years to speak to the general public about lawns. Whenever I speak to people who have little knowledge of turf management, I can always expect one question: "Is there anything that I can spray on my lawn so that I won't have to mow?"

Not having to mow has long been a dream of both the Saturday morning novice and the professional turfgrass manager. While the answer to the above question is a simple "no," there are a number of compounds that have the ability to slow the growth of grasses and consequently reduce the mowing requirements. This becomes particularly important on the golf course during periods of rapid growth such as in the spring for cool-season grasses and summer for warm-season grasses.

Table 1
Plant growth regulators that have been labeled for use on turf.

Common Name	Trade Name
Amidochlor	Limit
Chlorflurenol	Maintain CF125
Endothal	Endothal
Ethephon	Ethrel, Proxy
Flurprimidol	Cutless
Maleic hydrazide	Royal Slo-Gro
Mefluidide	Embark
Paclobutrazol	TGR, Turf-Enhancer, Trimmit
Trinexapac-ethyl	Primo MAXX

PGR Classification and Overview

Table 1 contains a list of both past and current plant growth regulating compounds (PGRs) that have been labeled for use on turf. The system by which PGRs are classified is undergoing change. The original system divided the compounds into two categories, Type I and Type II.[30]

Type I compounds are foliarly absorbed and inhibit cell division in the plant meristem.

Type II materials are usually crown and root absorbed. They suppress growth through the inhibition of gibberallic acid (GA), a naturally occurring plant hormone that reduces cell elongation. The Type II materials, which are also known as the GA inhibitors, include flurprimidol, paclobutrazol, and trinexapac-ethyl.

Most of the Type I PGRs are excellent seedhead inhibitors. Mefluidide is particularly well known for its ability to stop seedhead formation. Maleic hydrazide is also very effective at stopping seedhead formation. Both compounds tend to be somewhat phytotoxic and have limited use on high-maintenance turf. However, they are quite useful on low-maintenance turf such as roadsides. Mefluidide also is used to inhibit *Poa annua* seedhead formation in golf course turf. *Poa annua* seedhead suppression is difficult because it requires very precise applications of mefluidide and a thorough understanding of how the grass will react.

Type II compounds are usually less phytotoxic, although they also can cause some grass discoloration. The Type II compounds are not as effective in stopping seedhead formation as are the Type I materials, although they are quite effective at slowing growth and can be used to reduce the need for mowing if properly used. In the golf industry, one of the primary uses of flurprimidol and paclobutrazol has been the gradual removal of *Poa annua*. These GA inhibitors are known to have a greater inhibitory effect on *Poa annua* than on creeping bentgrass. With careful application and proper management techniques designed to discourage *Poa annua*, these materials may help increase the amount of bentgrass in the stand.

Trinexapac-ethyl is the newest of the Type II materials. Its advantage over the two older compounds is that it can be taken up through the foliage, whereas flurprimidol and paclobutrazol are primarily root absorbed. It has been used extensively on golf course fairways and to a limited extent on lawns to inhibit tissue growth and reduce the need for mowing. Trinexapac-ethyl has recently been labeled for *Poa annua* conversion programs.

The new classification system divides PGRs into classes A, B, C, and D.[31] Class A materials are GA inhibitors that interfere with GA production late in the biosynthetic pathway. Trinexapac-ethyl is the only Class A material at this time. Class B materials are those that inhibit GA early in the biosynthetic pathway. Flurprimidol and paclobutrazol are included in this class. Class C materials are mitotic inhibitors like maleic hydrazide, mefluidide, and amidochlor. Finally, Class D materials are PGRs that produce a phytotoxic growth regulating response at low levels and act as herbicides at higher levels. Two herbicides, chlorsulfuron (Telar) and glyphosate (Roundup), are examples of Class D compounds.

The newest material to reach the turf market is Proxy (ethephon), although it has been available for years in the floriculture and crop production markets. This material affects the growth of plants by releasing the plant hormone ethylene. It does not fit into any of the existing categories. The most striking effect is on Kentucky bluegrass, which undergoes some very unusual structural changes when treated with this product. Ethephon-treated bluegrass develops elongated internodes from the crown area and shortened leaves. The net effect is a stoloniferous Kentucky bluegrass that looks more like bermudagrass than bluegrass.[5,6] As is the case with other PGRs, the effect of the ethephon varies with species. Work is presently being conducted at Iowa State University to characterize these responses on cool- and warm-season grasses.[14] The effect of Proxy on creeping bentgrass fairways has been variable in recent studies, and more work will be required to fully evaluate this product for fairway use.[13, 22]

Growth reduction is generally the goal in the use of PGRs, but a number of other creative uses have been developed for these useful compounds in recent years. Some of these uses have been the result of studies in the scientific community, but others have come about as the result of observations made by turf professionals in the field.

Poa annua Control

Poa annua control remains a serious problem for golf course superintendents around the world. One of the creative uses of PGRs has been to use them as part of a carefully structured integrated program to reduce *Poa annua* in golf turf. As was mentioned earlier, this generally involves the GA-inhibiting (Type II) materials and has been most effective on bentgrass/*Poa annua* fairways. The GA inhibitors do not kill the *Poa annua*, but slow its growth more than that of the bentgrass. Over time, this results in an advantage to the bentgrass and reduction of the *Poa annua*. While this program became widely used in the 1990s, results have been quite variable by location. Success depends on the skill of the superintendents in adapting the program to their particular situation. Results also may vary with the *Poa annua* biotype in the region.[2, 24]

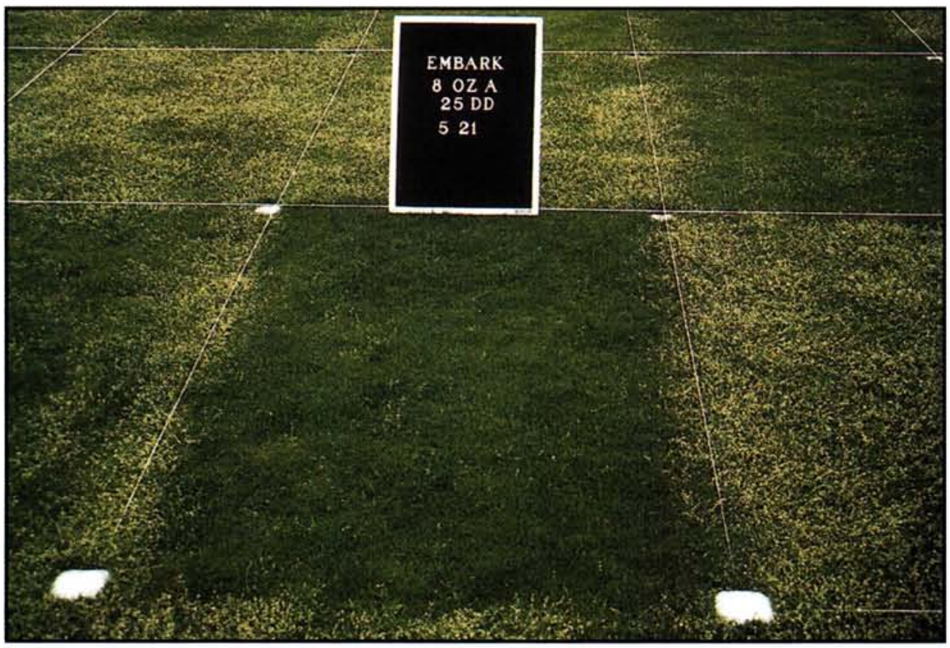
Flurprimidol (Cutless) was the first material to be used in this way, and paclobutrazol (TGR, Turf Enhancer, Trimmit) became the most widely used in the 1990s. In the spring of 2001, a new program that involves applications of paclobutrazol (Trimmit) in spring and fall and trinexapac-ethyl (Primo-MAXX) during the summer was also introduced to the market.

Seedhead suppression of *Poa annua* may also be a goal in the use of PGRs. The Type II materials are only moderately effective in reducing seedheads. Mefluidide (Embark) is by far the best seedhead suppressor, but its use is difficult and discoloration of the turf can easily occur. Ethephon (Proxy) has recently been tested as a seedhead suppressor. It has proven to be quite effective on some *Poa annua* biotypes in California, but results have been more variable in other regions of the country.

Color Enhancement

From the beginning of PGR use on the golf course, superintendents have observed color changes when these products are used. With the earlier Type I materials, there was often a negative effect and turf discoloration was common. With the GA inhibitors, however, improvements in turf color are often observed. This is particularly true with trinexapac-ethyl (Primo), which often results in a darker green color of treated turf.[21, 18]

Reduced growth and improved color are a very beneficial combination on highly maintained turf. As is usually the case with PGRs, this response can be highly variable.



Poa annua *contamination is a problem for golf course superintendents around the world. Embark is one plant growth regulator that effectively suppresses* Poa annua *seedheads, but there is potential for turf discoloration.*

Overseeding

PGRs have been employed as a tool to improve overseeding of cool-season grasses into warm-season turf. The goal is to slow the growth of the warm-season grass without inhibiting the establishment of the cool-season seedlings.[1, 11] Timing is critical to prevent inhibition of the cool-season seedlings[16, 29] and results may be quite variable.[12] Trinexapac-ethyl (Primo) tends to be one of the best PGRs for this purpose because of its foliar absorption and its reduced likelihood of inhibiting the cool-season seed germination.[8] A critical factor in using trinexapac-ethyl for this purpose is that it be allowed to dry on the bermudagrass tissue before overseeding takes place.[17] Current label recommendations suggest applying Primo one to five days before seeding.

Water Use

PGRs reduce growth, but does this translate into a reduction of water use? Research in Australia[15] showed a 25% to 30% reduction in water use rate on tall fescue treated with trinexapac-ethyl. There is a great deal of interest in this subject, particularly in arid regions, and more work is needed on a variety of species.

Freezing Damage

In northern regions, freezing damage can be a serious problem. PGRs slow growth, thicken cell sap, and may provide an antifreeze-like effect. Rossi and Buelow (1995) observed enhanced freeze tolerance of annual bluegrass treated with low rates of trinexapac-ethyl. However, Dunn *et al.* (1999) found no reduction in freezing damage on zoysiagrass treated with this product. Northern superintendents who often experience *Poa annua* loss during the winter may want to experiment with this idea.

Fungicides

One of the factors that limits fungicide efficacy is plant growth, or when the contacts are mowed off soon after application. PGRs tank-mixed with fungicides show promise in extending efficacy and in reducing the fungicide rates needed for disease control.[4, 25, 28, 32] Some PGRs may even directly suppress dollar spot on treated turf.[3]

Other Observations

Research has shown that PGRs can improve shade tolerance of certain species, particularly zoysiagrass.[10, 20, 21, 26, 27] Trinexapac-ethyl is now being widely used for this purpose in the transition zone of the United States and throughout the Orient.

Finally, trinexapac-ethyl has been shown to reduce clippings, prevent scalping, improve establishment of new sod,[23] and stimulate tillering of Kentucky bluegrass being grown for sod.[21]

These are only a few of the potential uses for PGRs in the turf industry, and other innovative ideas are likely to follow. A number of these uses had their origin from observations made by golf course superintendents and other turf professionals working with the materials in the field. Those with other creative ideas are encouraged to share them at meetings or on-line so that they can be further developed and tested.

The product works. A Poa annua*-infested sod strip was untreated before it was used down the center of a golf course fairway. The strip stands out amongst fairway turf that had been treated to suppress* Poa annua *seedheads.*

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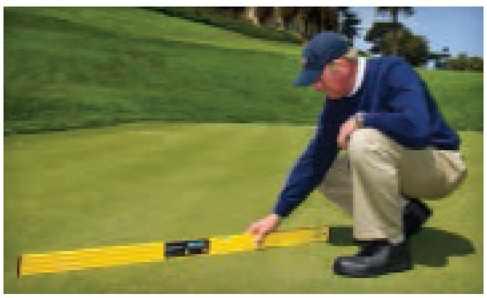

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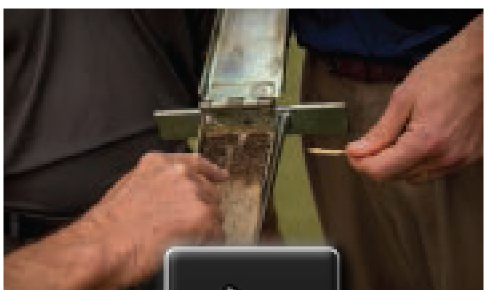

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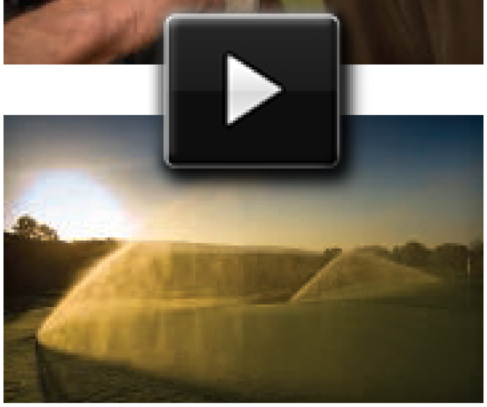

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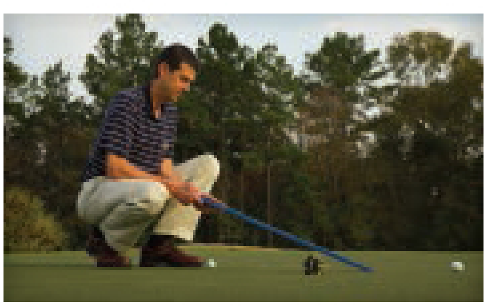

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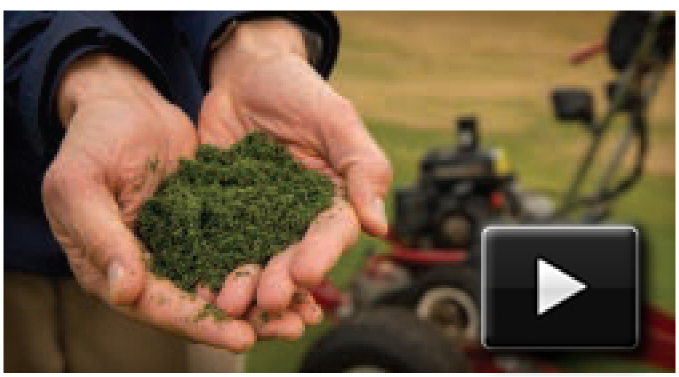

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Objective:

Examine each putting green and surrounding complex for several factors that predict putting green performance in the short and long term.

Tree Evaluation

Objective:

Examine golf course tree plantings as they relate to turfgrass health, playability, tree quality and aesthetics.

Bunker Evaluation

Objective:

Provide comprehensive, factual information and observations regarding the bunkers on the golf course.

Managing *Poa annua* Seedheads on Putting Greens

Successful seedhead inhibition can improve spring playability of *Poa annua* putting greens.

BY JEFFREY A. BORGER

This overview of the *Poa annua* seedhead plots at the Penn State University Blue Course clearly shows the impact of effective seedhead inhibition. The "brown" grass is actually just large numbers of emerged *Poa annua* seedheads.

Poa annua, commonly referred to as annual bluegrass, is widely adapted to putting greens in areas where cool-season grasses are maintained. Under optimum conditions, *Poa annua* provides a level of putting green quality that is second to none. Unfortunately, several maintenance challenges are prevalent with *Poa annua*. Winter injury, susceptibility to diseases such as anthracnose, and poor performance under hot, humid conditions increase the challenge of maintaining putting green performance throughout the year. Spring seedhead production reduces putting quality at a time when weather conditions allow for more aggressive *Poa annua* maintenance.

Fortunately, chemical options are available to reduce the impact of seedhead production on playing quality. This article provides a summary of many years of seedhead inhibition research and is applicable in areas where a distinct winter/spring transition occurs with a true flush of seedhead production in April and May. In areas such as California, where mild temperatures persist throughout the year, seedhead inhibition will be achieved with different programs.

Over the years, different formulations of Embark (mefluidide, now Embark Turf and Ornamental) have been the standard for inhibiting *Poa annua* seedhead production during the spring with late March or April applications. In recent years, the combination of Primo MAXX (trinexapac-ethyl) and Proxy (ethephon) also has been used to inhibit seedhead production with good results. Both Embark T/O and the Primo MAXX/Proxy combination can provide effective *Poa annua* seedhead inhibition leading to better spring putting quality. Both options provide advantages and disadvantages in terms of turf discoloration, especially when frost occurs after application.

Proper application timing is extremely critical. The goal is to control as many seedheads as possible with Plant Growth Regulators (PGRs). Research suggests that with proper timing, seedhead inhibition of *Poa annua* can routinely approach 90 percent, greatly enhancing spring putting quality. Common sense suggests that *Poa annua* could have a higher quality throughout the growing season if less energy is spent by the plant to produce seedheads, but research results have been variable.

Several different methods have been used to determine proper application timing. Proper timing is often stated to be when the seedhead is "in the boot" of the plant. However, this often is difficult for superintendents to determine in the field. Growing degree models also have been used with varying levels of success, depending upon spring weather. Another rule of thumb is that, generally, higher cut turf can be monitored for seedhead emergence to predict the ensuing emergence of seedheads on greens. When seedhead emergence is noted in fairway turf, emergence on putting greens will not be far behind. This is a general guideline, and daily monitoring of greens is necessary to determine "boot stage" of development. Start searching on southern exposures.

Ultimately, determining the proper application timing for seedhead inhibition is more art than science on a golf course. On a research plot, you are dealing with a single location, with consistent conditions, allowing for a very exact application timing to be employed. On a golf course, several different microclimates exist that confound application timing. Again, visual observation of *Poa annua* on a daily basis is critical.

Superintendents must determine when the greatest percentage of *Poa annua* is in the "boot stage" on greens, realizing that other growing stages also will be present. Once the seedhead has emerged, these PGRs will not suppress the seedheads of that particular plant. Conversely, very early applications of these PGRs will suppress seedheads, but cold weather conditions and the residual effects of the materials used must be considered. Many times there can be a warming of temperatures and plant growth followed by cold temperatures and even frost in the Northeast. If conditions are cold enough, *Poa annua* can become off-color, and if a PGR has been applied reducing growth, this off-color can be extended. Normally, this is only an aesthetic effect and not detrimental to the turfgrass community. Many areas of the Northeast can apply one application of Embark T/O and suppress seedheads during the peak spring season. If an early application of Embark is employed, a second application may be needed to achieve the same level of suppression.

Embark T/O has a long history of *Poa annua* seedhead suppression on putting greens. It is an effective material to suppress seedheads and overall plant growth. Embark T/O is generally applied to greens at 40 oz. of actual product per acre. When a second application is made, it is generally at a reduced rate. *Remember to always read and follow label directions before applying any pesticide!* When Embark is used alone, there can be some turfgrass discoloration that is transient in nature.

Superintendents who want less discoloration can choose to tank mix Embark T/O and Ferromec, which is a nitrogen and iron source that reduces this slight discoloration. There may also be a reduction in the amount of seedhead suppression with this tank mix. For example, one could see 90% seedhead suppression with Embark T/O alone. On the same research site, when Embark T/O is tank mixed with Ferromec, one might see suppression at 75% or 80%. In this example, both applications provide suppression, but one must balance whether appearance or playability is more important in a given situation.

In recent years, the combination of Primo MAXX and Proxy has proven to suppress *Poa annua* seedheads on putting greens. Research has found that the overall level of seedhead suppression is lower than that of Embark T/O, but there is no phytotoxicity following applications. Application rates have varied, but a good standard is 5 oz. of Proxy *per 1,000 square feet* and 5 oz. of Primo MAXX *per acre.* The Primo MAXX and Proxy combination can suppress seedheads at the 60% level. In some cases, research has revealed suppression at 75%, but this is not repeatable from year to year. This combination makes a smooth transition to the commonplace applications of Primo MAXX employed during the remainder of the growing season. If the superintendent chooses to use this mixture, note that a second application should be incorporated to maximize seedhead suppression two or three weeks following the original application. Again, these products should be applied at or before the "boot stage" of development.

Today, the use of PGRs is commonplace on many areas of the golf course. The superintendent often is asked to provide higher-quality playing conditions. As a result, the suppression of *Poa annua* seedheads also has become a more routine practice.

Following are a few questions to stimulate ideas for the seedhead control planning process. How much and where is the *Poa annua* on the putting greens? Which products should be considered to achieve the desired outcome? What, if any, level of turfgrass phytotoxicity can be accepted? If the greens historically have few seedheads, can Primo MAXX and Proxy be a viable option for suppression? Once these questions are answered, a viable seedhead control program can be developed to improve spring playability on *Poa annua* or mixed *Poa annua*/creeping bentgrass putting greens. Just remember that spring weather patterns can have a dramatic impact on application timing and the ultimate results achieved.

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Research *You Can Use*

Field Testing Plant Growth Regulators and Wetting Agents for Annual Bluegrass Seedhead Suppression

Researchers use Chicago-area golf courses to explore suppressing annual bluegrass flowering.

BY RANDY KANE AND LEE MILLER

Left: Research supported by the Chicago District Golf Association tested the ability of plant growth regulators and wetting agents to suppress annual bluegrass seedhead formation. Above: Heavy *Poa annua* seedhead formation on Midwest putting greens is typical in mid to late May in most years.

Many of the annual bluegrass biotypes inhabiting the golf courses of Illinois have a *winter annual* life cycle. That is, these biotypes germinate from seed in autumn, overwinter in a vegetative state, flower and set seed in the spring, and then decline or completely die out during the heat of summer.

Where annual bluegrass is a significant component in a turf, profuse seeding may occur in late April through May and can become objectionable for several reasons. First, profuse seeding can turn an annual bluegrass-contaminated green or fairway almost white in color, prompting questions about grass health. Second, putting greens with significant annual bluegrass populations provide very poor putting surfaces during spring flowering. Seedheads adversely affect ball roll, causing greens to become slower and more bumpy. Third, heavy seeding of annual bluegrass contributes to the seedbank in surface soil and thatch layers, thus promoting the long-term survival and spread of the species.

There is a growing body of evidence that suggests heavy seeding may not be beneficial for the near-term survival of flowering annual bluegrass. Seed production may divert photosynthate away from vegetative tissues (leaves and roots) to the flowers, resulting in reduced root depth and shoot growth after seeding. Annual bluegrass that hasn't set seed (e.g., in treated plots) is usually better able to survive summer stresses than plants that have flowered and set seed (2). It is interesting to note that most of the plants identified as *perennial biotypes* of annual bluegrass produce less seed than *annual biotypes*, which may contribute to their longer-term, perennial habit.

Chemical seedhead suppression can help maintain the color and playability of fairways, as well as the speed and trueness of putting greens. Also, many superintendents feel that by reducing seed set and the annual contributions to the seedbank, other chemical and management programs used to reduce or eliminate annual bluegrass from cool-season turf may become more effective. There also is a great deal of interest in trying to preserve the purity of newly renovated turf by keeping nearby annual bluegrass from contaminating the renovated site (e.g., a resurfaced putting green).

TECHNIQUES TO INHIBIT ANNUAL BLUEGRASS FLOWERING

How do you reduce or suppress annual bluegrass seed set in the spring? Several herbicides and plant growth regulators are known to inhibit seeding of *Poa* species and other grasses, including older products like maleic hydrazide, mefluidide, and endothal (Table 1). However, most products used in annual bluegrass programs have problems with consistency of seedhead suppression, length of time seedheads are suppressed, or phytotoxicity. Also, application timing and proper stage of plant growth are critical for best seed inhibition, and calendar dates for application may vary widely from year to year. Note that there is a "base-50" growing-degree-day prediction model for timing of the first spray for seedhead suppression (3), but this model seems to be as unpredictable as the annual bluegrass itself (Table 2).

Historically, the best results for seedhead suppression on annual bluegrass fairways have been found using mefluidide ("Embark") (1, 5). However, timing and phytotoxicity problems have limited its use, especially on greens-height turf. Many superintendents have tried early spring applications of gibberellin inhibitor plant growth regulators (PGRs) such as paclobutrazole ("Trimmit") or flurprimidol ("Cutless") to try to slow the encroachment of annual bluegrass into bentgrass turf. They reported some seedhead suppression following early season treatments, but seedhead suppression usually is not the primary goal of these applications.

A few adventurous superintendents have also used the wetting agent Aqua-Gro L (5) to limit spring flowering of annual bluegrass, and they have found that Aqua-Gro is less phytotoxic than Embark, but it provides more variable results. (Aqua-Gro L is no longer manufactured.)

Embark Turf & Ornamental can cause discoloration and thinning of creeping bentgrass mowed at greens height-of-cut (below pen).

Preliminary field tests have suggested the ethephon ("Proxy") has good activity for annual bluegrass seedhead suppression (4). Proxy is a new PGR for the turf market, but it has been available in agricultural applications for years. Proxy may be safer and have more timing flexibility than Embark, and it could be a potential substitute for Aqua-Gro L. Proxy reportedly has the tendency to make treated turf lighter green to yellow-green, but this can be counteracted to some extent with iron applications. Also, tank-mixes of Proxy plus trinexepac-ethyl (Primo) have shown good results with less turf discoloration.

PRODUCTS TESTED AND APPLICATION TECHNIQUES

Three golf course sites were treated with PGRs and wetting agents in April and May of 2000-02, including both greens- and fairway-height turf. Initial treatments were timed to coincide with flowering of the earliest annual bluegrass biotypes. Individual plots were 40-50 sq. ft. in size and were replicated two or three times, depending on space available. Treatments were applied with a CO_2-powered backpack sprayer (35 psi, flat fan nozzles).

Proxy was tested alone and in tank mixes with Primo and Trimmit. Single and multiple applications of Proxy were made at 5-7.5 fl. oz. per 1,000 sq. ft. rates. Primo was applied alone and in tank mixes at 5-10 fl. oz. per acre. Trimmit was applied at rates ranging from 6-8 fl. oz. per acre. Aqua-Gro L

has been tested for a number of years on putting greens at 8 fl. oz. per 1,000 sq. ft., usually with follow-up applications at 4-8 fl. oz. per 1,000 sq. ft. one week later.

The wetting agent Cascade was also included in the study to see if a different type of wetting agent chemistry could inhibit seedheads (note that the manufacturer makes no claims of seedhead control). Embark (Turf & Ornamental Growth Regulator formulation) at 1.3 fl. oz. per 1,000 sq. ft. was included as a standard, and to test for phytosafety on greens-height turf.

SUMMARY OF RESULTS FROM EARLY STUDIES

A general overview of field test data from Chicago area trials in 2000-01 on greens-height turf can be found in Table 3. Note that the percent seedhead

Table 1
Chemicals that have been used for annual bluegrass (*Poa annua* L.) seedhead suppression

Trade Name	Common Name	PGR Mode of Action
"MH" or SlowGro	Maleic hydrazide	Type I cell division
Endothal	Endothal	Type I cell division
Embark	Mefluidide	Type I cell division
Prograss	Ethofumesate	Type I (?)
Enhancer, Trimmit	Paclobutrazole	Type II GA inhibitor
Cutless	Flurprimidol	Type II GA inhibitor
Primo	Trinexepac-ethyl	Type II GA inhibitor
Proxy	Ethephon	Ethylene effects
Aqua-Gro L	NA (wetting agent)	Unknown

Table 2
Comparison of base-50 growing-degree-day annual bluegrass model to first visible flowering over the last four years

Year	Date that $GDD_{50} \geq 50$	First Visible Flowering
2002	April 15	April 24-28
2001	April 12	April 27-29
2000	April 7 or April 24	May 3-7
1999	April 4	April 15

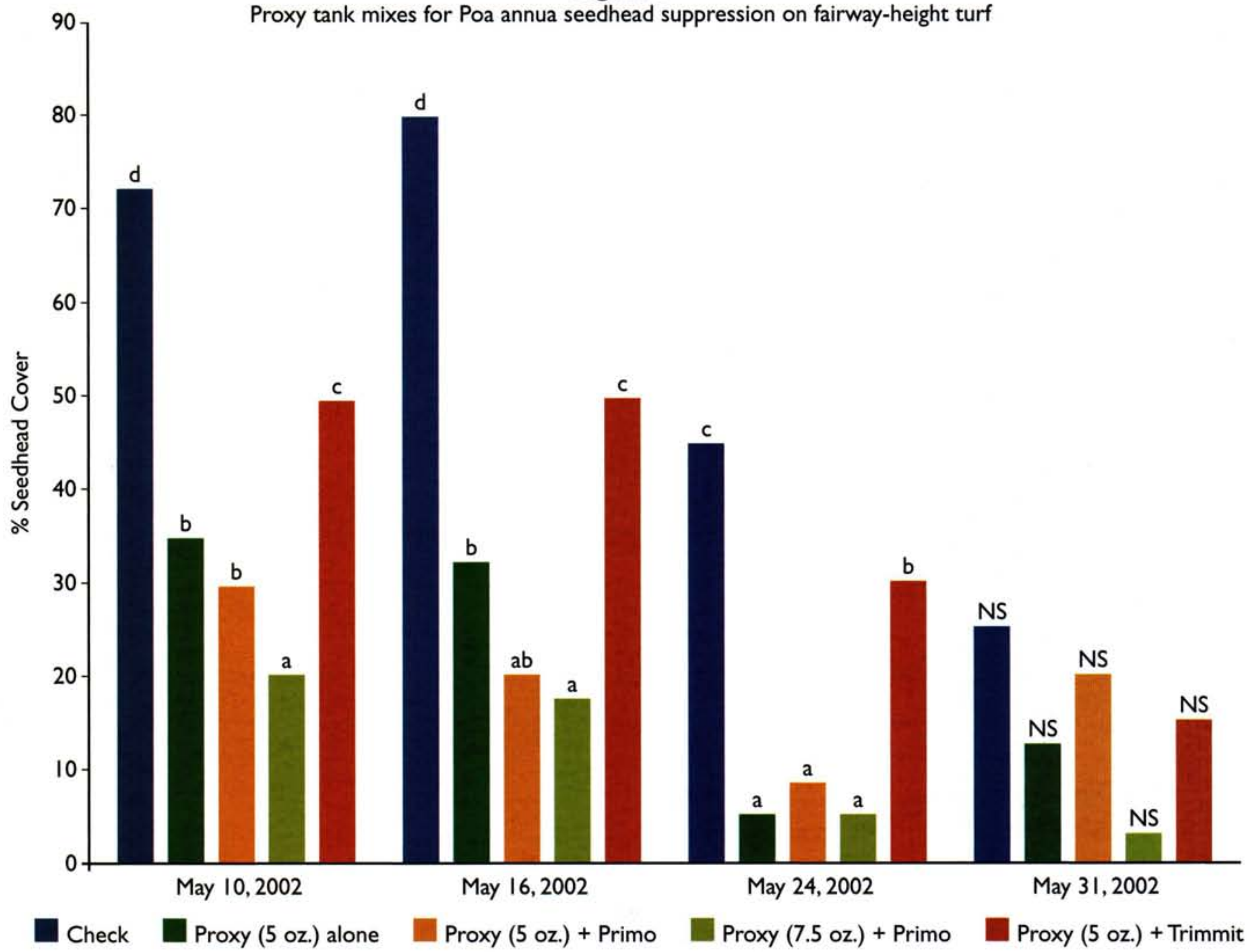
Table 3
General overview of percent annual bluegrass seedhead suppression by PGRs and wetting agents for tests conducted in the Chicago suburbs (2000-01)

Product	No. of Applications	Rate per 1,000 sq. ft.	% Seedhead Suppression*		
			May 10	May 24	June 1
Aqua-Gro L	3	8,4,4 fl. oz.	55	50	25
Cascade	2	4 fl. oz.	25	0	20
Trimmit	2	0.18 fl. oz.	0	0	0
Primo	2	.125 - .25 fl. oz.	0	15	0
Proxy	1-2	5 - 7.5 fl. oz.	80	85	80
Proxy+Primo	1-2	5 + .125 fl. oz.	80	85	80
Embark T&O	1	1.3 fl. oz.	90	95	80

*Data show percent reduction in seedheads compared to untreated plots.

Figure 1

Proxy tank mixes for Poa annua seedhead suppression on fairway-height turf



inhibition is an average of several tests, and results can vary greatly with weather conditions, application timing, and annual bluegrass biotypes present in treated areas. Embark is consistently the best flower suppressor, but phytotoxicity (primarily on creeping bentgrass) remains a major concern in northern Illinois. Phytotoxicity of Embark treatments was expressed as a dark blue-green to brown color, with some thinning of the stand. Once warmer weather arrived, turf color and density recovered.

Proxy and Proxy + Primo treatments provided seedhead suppression approaching that of Embark in our trials in 2000 and 2001. In some cases, suppression with split applications of Proxy lasted longer than single Embark applications. However, higher rates or repeat applications of Proxy caused yellowing and thinning of treated turf, especially at greens height. Note that repeat Proxy applications were made only 7 to 10 days apart; less discoloration has been observed in other tests if the interval between applications is 28-35 days (4). Tank mixing Proxy with Primo appeared to reduce the discoloration and thinning of turf, although further testing will be required to confirm the effect.

Of the other products/rates tested, only Aqua-Gro L exhibited significant seedhead suppression, and the effect was short-lived and inconsistent from site to site and season to season. The anti-gibberellin growth regulators Primo and Trimmit did not appear to inhibit seedhead formation, and in some situations, these treatments appeared to have more seedheads than check plots. This effect could be due to stunting of the seed stalk to the point where the seedheads remained below the cutting height and were not removed by mowing.

OBSERVATIONS FROM 2002 STUDIES

For 2002 greens-height trials, we concentrated on Proxy alone or in tank mixes with Primo or Trimmit (Table 4). We also began a second set of treatments a week later to see if a later application was as effective as a well-targeted first application. The Proxy and

Table 4

Percent of annual bluegrass seedhead suppression on putting green turf by Proxy alone and in tank mixes with anti-gibberellin PGRs (2002 studies)

Product	Rate per 1,000 sq. ft.	Application Date	% Seedhead Suppression* May 10	May 24	June 1
Proxy	5 fl. oz.	April 18	75	56	40
Proxy	5 fl. oz.	April 24	8	44	48
Proxy + Primo	5 + .125 fl. oz.	April 18	83	74	52
Proxy + Primo	5 + .125 fl. oz.	April 24	33	78	68
Proxy + Trimmit	5 + .14 fl. oz.	April 18	42	70	68
Proxy + Trimmit	5 + .14 fl. oz.	April 24	16	74	70

*Data show percent reduction in seedheads compared to untreated plots.

Proxy+ tank mixes did not perform as well as in the previous two years. On certain rating dates, the level of seedhead suppression was hovering around 50 percent, with the best levels around 70% suppression. Previous tests provided about 90% suppression. Variability in seedhead suppression with PGRs is common (3, 5) and may be due to differing weather and application timing parameters, as well as to the inherent variability of annual bluegrass biotypes. Proxy treatments applied a week later than the supposed target date still performed well once the time lag was taken into account.

Finally, we took a look at some Proxy tank mixes sprayed on a mixed annual bluegrass/creeping bentgrass fairway (Table 5 and Figure 1). Taking the Proxy rate up to 7.5 fl. oz. per 1,000 sq. ft. improved the seedhead suppression, and no noticeable phytotoxicity was observed at this rate when tank mixed with Primo at 10 fl. oz. per acre. Proxy does not have a separate label rate for fairway treatments or a recommended rate for putting greens on the 2002 pesticide label. It is likely that some broader uses and application rates will appear on future labels.

Shade patterns influence *Poa annua* growth and its competition with bentgrass.

CONCLUSIONS AFTER THREE YEARS OF TESTING

After three years of testing products for annual bluegrass seedhead suppression, some conclusions can be reached.

Table 5

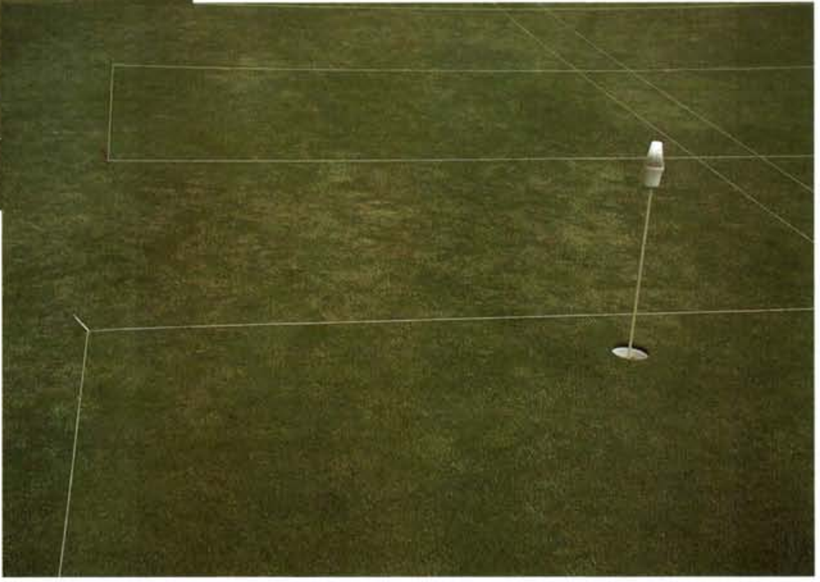
Percent annual bluegrass seedhead suppression on fairway turf — 2002*

Product	Rate per 1,000 sq. ft.	% Seedhead Suppression** May 10	May 16	May 24	May 31	June 7
Proxy	5 fl. oz.	52	59	89	48	54
Proxy + Primo	5 + .25 fl. oz.	59	75	80	20	31
Proxy + Primo	7.5 + .25 fl. oz.	73	78	89	88	92
Proxy + Trimmit	5 + .28 fl. oz.	32	38	33	40	0

*Application date for all treatments was April 23, 2002.
**Data show percent reduction in seedheads compared to untreated plots.

- Seedhead production in annual bluegrass is detrimental for various reasons, including poor playability, aesthetics, and reduced plant vigor.
- The most consistent seedhead suppression follows treatments with mefluidide or ethephon, although both chemicals have limitations regarding application timing or possible phytotoxicity.
- Embark can cause discoloration and thinning of bentgrass following cold weather, but it remains the best product for seedhead suppression, especially on

Higher rates of Proxy (without Primo or chelated iron) caused some discoloration of treated turf mowed at putting green height. Patchy seedhead development is evident in the check plot at left.



Visible seedheads were evident in untreated plots when compared to surrounding treatments that demonstrated varying abilities to suppress seedheads.

fairways, where some phytotoxicity is tolerable.

- Proxy can be nearly as effective as Embark for seedhead suppression, but results are variable from year to year and from site to site.
- Proxy can cause some objectionable color and growth effects, but tank mixes with Primo or other PGRs may alleviate some of these problems.
- If Proxy (+Primo) applications are made early in spring, a follow-up application 4-5 weeks after the first may be beneficial to maintain the seedhead suppression into June.
- Wetting agents gave inconsistent results and were approximately 50% as effective as mefluidide or ethephon, at best.
- Anti-gibberellin PGRs such as paclobutrazole and trinexepac-ethyl did not significantly reduce seedheads in our studies.
- Seedhead suppression can be highly variable from year to year or site to site because of weather fluctuations, application timing, and annual bluegrass variability.

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