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RESEARCH

Annual Bluegrass Control on Putting Greens from Three or Four Years of Season-long Applications of Herbicides or Plant Growth Regulators in Three States

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Abstract

Annual bluegrass (*Poa annua* L.) may be the most troublesome and studied weed on golf courses in the United States. Given the genetic variability of annual bluegrass and its ability to adapt to different environments, it is important to understand how control methods vary across environments or regions. Our objective was to evaluate seven season-long regimes of herbicide or growth regulators for annual bluegrass control in creeping bentgrass (*Agrostis stolonifera* Huds.) putting greens over 3 or 4 years in three states in the midwestern United States. Depending on the product, applications were made as often as every 2 weeks from April through September. Effectiveness of treatments varied widely by location and time, with treatments most effective in Indiana and Nebraska. Paclobutrazol was the most effective plant growth regulator for annual bluegrass control, followed closely by flurprimidol. Intermediate at reducing annual bluegrass was flurprimidol + trinexapac-ethyl and trinexapac-ethyl was ineffective. Among herbicides, the now discontinued experimental cumyluron was most effective and four applications of bispyribac-sodium at 2 oz/acre every 2 weeks in August and September was more effective than 1 oz/acre applied every 2 weeks from May through September or applications of cumyluron. Though a number of products will reduce annual bluegrass on golf greens, overall control was relatively low, reinforcing the need to maximize cultural practices before attempting chemical control. Furthermore, our results reinforce the importance of superintendents' experimenting and refining treatment regimes in their specific location to maximize efficacy.

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Abbreviations: ABG, annual bluegrass; AUPPC, area under percent *Poa* curve; CBG, creeping bentgrass; GA, gibberellic acid.

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ANNUAL BLUEGRASS (*Poa annua* L.; ABG) may be the most troublesome weed on golf courses worldwide. Annual bluegrass's genetic diversity, ability to adapt to varying environments, and reproductive capacity from seed enable it to thrive in golf course turf. A number of herbicides and growth regulators are labeled and effective for ABG control on fairway-height cool-season grasses. Paclobutrazol is a growth regulator that inhibits gibberellic acid (GA), and multiple applications effectively reduce ABG cover in fairway-height creeping bentgrass (*Agrostis stolonifera* Huds.; CBG) (Isgrigg et al., 1999a, 1999b; Johnson and Murphy, 1995, 1996; McCullough et al.,

Table A. Useful conversions.

To convert Column 1 to Column 2, multiply by	Column 1 Suggested Unit	Column 2 SI Unit
0.304	foot, ft	meter, m
2.54	inch	centimeter, cm (10^{-2} m)
0.405	acre	hectare, ha
9.29×10^{-2}	square foot, sq ft	square meter, sq m
3.78	gallon, gal	liter, L (10^{-3} m^3)
2.96×10^{-2}	ounce (liquid), oz	liter, L (10^{-3} m^3)
28.4	ounce (avdp), oz	gram, g
454	pound, lb	gram, g (10^{-3} kg)
6.90	pound per square inch, lb/sq inch	kilopascal, kPa

2005; Woosley et al., 2003). Flurprimidol is also a GA inhibitor and reduces ABG cover in fairway-height cool-season turfs (Bigelow et al., 2007; Isgrigg et al., 1999a, 1999b), and effect on ABG depends on other management factors (Gaussoin and Branham, 1989). Trinexapac-ethyl is a GA inhibitor and widely used as a growth regulator in turf, but has limited effect on ABG control (Rossi, 2001; McCullough et al., 2005; Bigelow et al., 2007). Postemergence herbicides are also effective for controlling ABG in cool-season turf maintained at fairway height, including bispyribac-sodium (Askew et al., 2004; McCullough and Hart, 2006) and ethofumesate (Coates and Krans, 1986; Dernoeden and Turner, 1988; Meyer and Branham, 2006).

Controlling ABG on golf putting greens is more difficult than on fairways because of fewer labeled products and potential injury to CBG. The growth regulators paclobutrazol or flurprimidol are the most commonly used to reduce ABG in putting greens. Johnson and Murphy (1995, 1996) reduced ABG cover by up to 85% in CBG putting greens in Georgia with three or four spring applications plus three or four fall applications of paclobutrazol or flurprimidol made at 4-week intervals. Isgrigg et al. (1999a, 1999b) used applications of paclobutrazol or flurprimidol in spring and/or fall to reduce ABG populations by up to 80% in North Carolina. More recently, various regimes of paclobutrazol applied only in the spring provided up to 46% control of ABG in North Carolina (Jeffries et al., 2013). Bell et al. (2004) reduced ABG cover in CBG putting greens in Oklahoma by up to 31% over 2 years with four fall applications of paclobutrazol followed by five spring applications, all at 2-week intervals of 6.4 oz/acre of the 2SC formulation. Most of the previous research was done in southern states, where applications of growth regulators are curtailed during high temperatures of the summer. Few reports are available on season-long applications to control ABG on putting greens in cooler climates. Two years of season-long applications of paclobutrazol or flurprimidol made at 2-week intervals increased CBG cover up to 39% in CBG–ABG putting greens in Idaho and Washington (Baldwin and Brede, 2011). In this same study, season-long applications of the commercially available combination of flurprimidol + trinexapac-ethyl provided marginal to no control of ABG depending on rate and location. There are currently no postemergence herbicides labeled for ABG control on putting greens, but bispyribac has reduced ABG in putting greens–height turf in research trials, albeit with varying levels of discoloration or injury (McCullough and Hart, 2010; Teuton et al., 2007).

Annual bluegrass control studies are traditionally on one or two experimental sites and often only last for 1 or 2 years. However, given the variability of this species from site to site and its ability to adapt to environments, it is important to understand long-term control methods and how these control methods vary over different sites and environmental conditions. Therefore, our objective was to evaluate seven season-long regimes of herbicide or growth regulators for ABG control in creeping bentgrass putting greens over 3 or 4 years in three states in the midwestern United States.

STUDIES IN THREE STATES

Duplicate studies were conducted on CBG–ABG turf maintained as putting greens at the Wm. H. Daniel Turf Center at Purdue University in West Lafayette, IN; the Robert W. Hancock Turfgrass Research Center at Michigan State University in East Lansing, MI; and at Firethorn Golf Club in Lincoln, NE. Site and management details are listed in Table 1. All experiments were arranged in a randomized complete block design with three replications. Individual plots measured 5 by 5 ft.

Herbicides and growth regulators were applied season-long to the same plots according to recommendations from the label, company representatives, or golf course superintendents. Products evaluated were bispyribac-sodium (Velocity, Valent), paclobutrazol (Trimmit 2SC, Syngenta), flurprimidol (Cutless MEC, SePro Corporation), flurprimidol + trinexapac-ethyl (Legacy, SePro Corporation), or trinexapac-ethyl (Primo Maxx, Syngenta). Cumyluron (HM9930, Helena Chemical Company) was also included because it was a promising experimental at the initiation of the study, but development was discontinued. Bispyribac-sodium was included because

Table 1. Location description and management of sites evaluating season-long programs for annual bluegrass control on greens-height turf.

Environment/ management	Nebraska	Michigan	Indiana
Age of stand at initiation of study	20 yr	11 yr	10 yr
Creeping bentgrass cultivar	Penncross	Penncross	Penncross
Source of annual bluegrass	Natural infestation	Natural infestation	Natural infestation
Soil type	USGA† sand/peat	93% sand, 6.5% silt, 0.5% clay	Native soil (silt loam)
Mowing	0.105 inch 7 times/wk	0.125 inch 5 times/wk	0.156 inch 6 times/wk
Fertility	3 lb N/1000 sq ft/yr	3 lb N/1000 sq ft/yr	3 lb N/1000 sq ft/yr
Irrigation	As needed to prevent drought stress	As needed to prevent drought stress	As needed to prevent drought stress
Verticut	4–5 times during growing season	2–3 times during growing season	None during this experiment
Aerification	Solid tine (April and August)	None during this experiment	None during this experiment
Topdressing	Light USGA sand every 2 wk	Light USGA sand every week	Light USGA sand every 4 wk

† USGA, United States Golf Association.

Table 2. Treatments evaluated to control annual bluegrass in identical experiments in three states over 2009–2013.

Active ingredient	Mode of action	Brand name and formulation	Rate	Rate	Application frequency	Application dates	Total applications per year
			oz/acre	lb a.i./acre			
Bispyribac-sodium	B(2) acetolactate synthase (ALS) inhibitor†	Velocity 17.6 SG	1	0.011	2 wk	May–Sept.	8
Bispyribac-sodium		Velocity 17.6 SG	2	0.022	2 wk	Aug.–Sept.	4
Cumyluron	Z(27) unknown†	HM9930	130	3.0	5 mo	Apr., Aug.	2
Paclobutrazol	Gibberellic acid biosynthesis inhibitor, Class B‡	Trimmit 2SC	8 16	0.125 0.25	2 wk 2 wk	Apr.–May, Aug.–Sept. June–July	8 4
Flurprimidol	Gibberellic acid biosynthesis inhibitor, Class B‡	Cutless MEC	8 16	0.081 0.163	2 wk 2 wk	Apr.–May May–Aug.	5 7
Flurprimidol + trinexapac-ethyl	Gibberellic acid biosynthesis inhibitor, Class B + A‡	Legacy	10	0.118	2 wk	Apr.–Sept.	12
Trinexapac-ethyl	Gibberellic acid biosynthesis inhibitor, Class A‡	Primo Maxx	11	0.086	2 wk	Apr.–Sept.	12
Untreated	–	–	–	–	–	–	–

† For each herbicide, the letter and number is a descriptive code for the mode of action that follows. This classification system (codes) was developed by the Herbicide Resistance Action Committee (uppercase letters) and the Weed Science Society of America (superscript number).

‡ Class A plant growth regulators (PGRs) interfere with the production of gibberellins late in the biosynthetic pathway. Class B PGRs interfere with the production of gibberellins early in the biosynthetic pathway.

it had pending label changes when this experiment was initiated that would have allowed use on putting greens, but those changes are currently discontinued. Products were applied up to 12 times per year on 2-week intervals, and application rates and frequencies are listed in Table 2. Applications began in April 2009 in Indiana and Michigan and in April 2010 in Nebraska and continued through fall 2012 at all locations. Applications were made with CO_2–powered backpack sprayers in 88 gal/acre water at 30 psi, with a three-nozzle (8002VS flat fan, Teejet Spraying Systems, Wheaton, IL) spray boom.

Data collected included transect counts of ABG taken during peak seedhead production in spring before the first application and in spring 2013 following the last

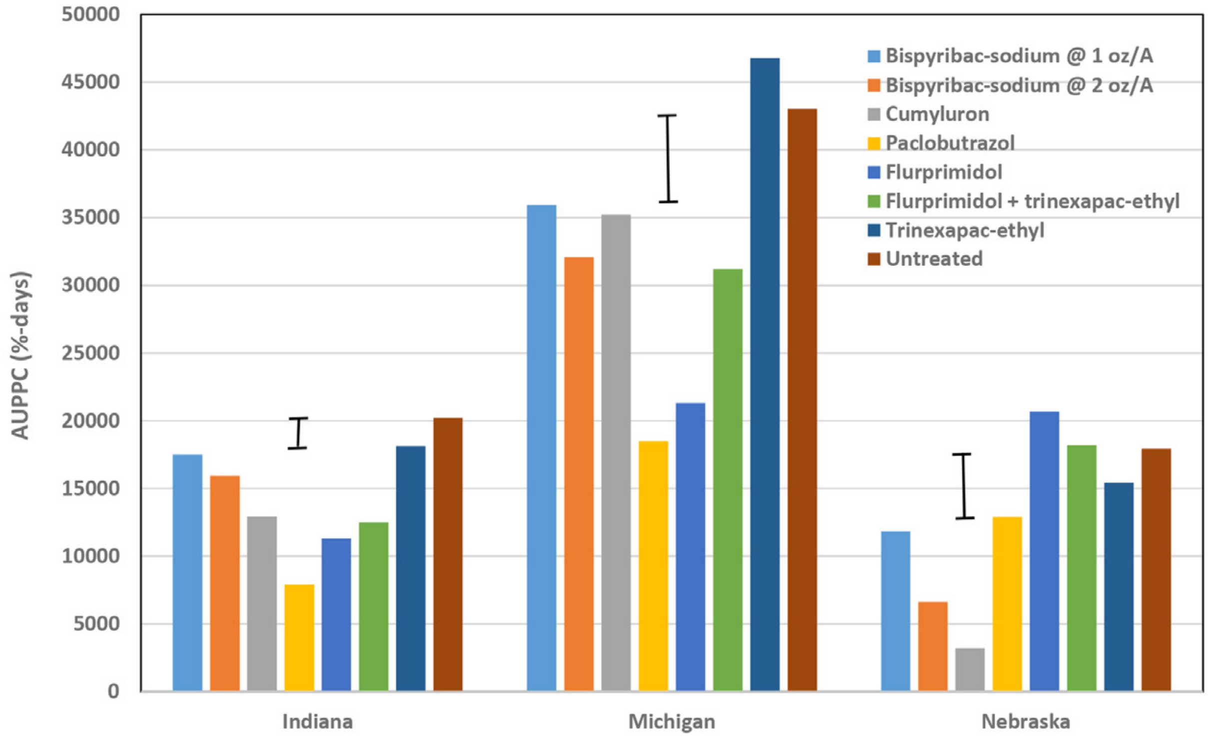

Figure 1. Area under percent *Poa* curve (AUPPC) calculated from all visual ratings and vertical point quadrat measurements of percent cover from study initiation through the final rating in May 2013. Error bar indicates Fisher's least significant difference at $P \leq 0.05$ within each location. Treatments were applied up to 12 times per year for 3 years in Nebraska and 4 years in Indiana and Michigan. A = acre.

year of applications. Estimates of ABG were taken using a modification of the vertical point quadrat method (Gaussoin and Branham, 1989), where a 4- by 4-ft frame or larger was laid over the plots with an interval filament grid of 49 or 64 intersections depending on location. The total number of times ABG was present under each intersection was recorded for each plot, and percent cover was calculated. Visual ratings of ABG cover, turfgrass phytotoxicity, and quality were also taken throughout each growing season. All visual and vertical point quadrat measurements of percent cover were plotted over days after study initiation through the final rating in May 2013 and presented as area under percent *Poa* curve (AUPPC) as in Woosley et al. (2003). The AUPPC was calculated as:

$$\text{AUPPC} = \sum_{i=1}^{n-1}\left[\left(X_{i+1} + X_i\right)/2\right]\left(t_{i+1} - t_i\right)$$

where X_i = percent ABG cover at the *i*th observation, t_i = days after the initiation of the study, and n = number of observations (Woosley et al., 2003). Similar to area under the disease progress curve (Campbell and Madden, 1990), these values provide long-term summaries of ABG cover, with AUPCC values declining with decreasing ABG cover.

Analysis of variance was performed using PROC ANOVA in SAS (SAS Institute, 2009). Significant treatment × location interactions occurred and thus locations were analyzed separately. Mean separation was determined using Fisher's least significant difference at $P \leq 0.05$. Annual bluegrass cover was rated 91 times across the three states and so it is unmanageable to discuss the entire data set. Therefore, we will discuss primarily the spring quadrat data and AUPPC.

TREATMENT EFFECTS DIFFER WIDELY ACROSS STATES

In Indiana, all treatments except trinexapac-ethyl reduced AUPPC compared with the untreated check by the end of the study, with paclobutrazol being most effective followed by flurprimidol, flurprimidol + trinexapac-ethyl, or cumyluron (Fig. 1). However, only three treatments reduced ABG cover from the initial to the final ratings. Paclobutrazol reduced ABG cover to 2% by May 2013, which was a 95% reduction over the course of the study, while flurprimidol or cumyluron also reduced ABG cover by >75% during the study (Table 3). The apparent difference between AUPPC and percent ABG change over the course of the study was largely due to a sharp decrease in ABG cover across the entire study that occurred in 2010, which was an abnormally warm and wet summer. The ABG did not recover in the last two seasons of the study as 2012 was also abnormally warm and even the untreated control showed a 50% decrease in ABG cover from initiation to the final rating date (Table 3). Treatments did not cause significant damage to CBG, but did reduce overall turf quality of the

Table 3. Cover of annual bluegrass (ABG) taken during spring seedhead production during and after 4 yr of season-long applications of herbicides or growth regulators to creeping bentgrass/ABG maintained at putting green height in West Lafayette, IN.

Treatment	Applications/year and rate	May 2009†	May 2010	May 2011	April 2012	May 2013	May 2013
		% cover‡					% change§
Bispyribac-sodium	8 @ 1 oz/acre	43¶	49 ab#	18 abc	10	26 a	−37 a
Bispyribac-sodium	4 @ 2 oz/acre	45	40 bc	15 bc	7	19 ab	−58 abc
Cumyluron	2@ 130 oz/acre	56	47 ab	11 cd	3	6 cd	−89 d
Paclobutrazol	8 @ 8 oz/acre 4 @ 16 oz/acre	39	15 d	2 d	5	2 d	−95 d
Flurprimidol	5 @ 8 oz/acre 7 @ 16 oz/acre	41	26 cd	9 cd	2	11 c	−75 cd
Flurprimidol + trinexapac-ethyl	12 @ 10 oz/acre	34	37 bc	11 cd	6	13 bc	−61 bc
Trinexapac-ethyl	12 @ 11 oz/acre	43	56 a	25 ab	15	19 ab	−56 abc
Untreated	–	49	54 a	28 a	15	22 a	−50 ab

† May 2009 ratings were taken before initiation of treatments.

‡ Annual bluegrass cover was estimated with vertical point quadrat method where a 4- by 4-ft frame was laid over the plots with an interval filament grid of 49 intersections. The total number of times ABG was present under each intersection was recorded for each plot and percent cover was calculated.

§ Percent change from the initial ABG cover, calculated as [(ABG cover in final spring rating − ABG cover in initial spring rating)/ABG cover in initial spring rating] × 100.

¶ Means of three replications.

Means within a column followed by the same letter are not significantly different according to Fisher's least significant difference at $P \leq 0.05$.

Table 4. Cover of annual bluegrass (ABG) taken at spring seedhead production during and after 4 yr of season-long applications of herbicides or growth regulators to creeping bentgrass/ABG maintained at putting green height in East Lansing, MI.

Treatment	Applications/year and rate	May 2009†	May 2010	May 2011	April 2012	May 2013	May 2013
		% cover‡					% change§
Bispyribac-sodium @ 1 oz/acre	8 @ 1 oz/acre	27¶	39 bc#	44 a	52 ab	50 a	93 a
Bispyribac-sodium @ 2 oz/acre	4 @ 2 oz/acre	25	33 c	38 ab	51 ab	46 a	88 ab
Cumyluron	2@ 130 oz/acre	29	43 ab	44 a	44 b	40 ab	45 bc
Paclobutrazol	8 @ 8 oz/acre 4 @ 16 oz/acre	27	31 c	12 c	14 d	28 c	5 c
Flurprimidol	5 @ 8 oz/acre 7 @ 16 oz/acre	30	39 bc	26 bc	27 c	33 bc	19 c
Flurprimidol + trinexapac-ethyl	12 @ 10 oz/acre	25	42 ab	44 a	51 ab	46 a	92 a
Trinexapac-ethyl	12 @ 11 oz/acre	30	49 a	54 a	60 a	49 a	74 ab
Untreated		28	49 a	51 a	61 a	49 a	81 ab

† May 2009 ratings were taken before initiation of treatments.

‡ Annual bluegrass cover was estimated with vertical point quadrat method where a 5- by 5-ft frame laid over the plots with an internal filament grid of 64 intersections. The total number of times ABG was present under each intersection was recorded for each plot and percent cover was calculated.

§ Percent change from the initial ABG cover, calculated as [(ABG cover in final spring rating − ABG cover in initial spring rating)/ABG cover in initial spring rating] × 100.

¶ Means of three replications.

Means within a column followed by the same letter are not significantly different according to Fisher's least significant difference at $P \leq 0.05$.

plots at times due to thinning of ABG and perhaps CBG by growth regulators (data not shown). Trinexapac-ethyl or flurprimidol + trinexapac-ethyl improved quality of CBG–ABG stand occasionally compared with the control (data not shown) as previously reported (McCullough et al., 2005; Bigelow et al., 2007).

Paclobutrazol or flurprimidol were most effective reducing AUPPC in Michigan, while trinexapac-ethyl was again the only treatment that did not reduce AUPPC compared with the untreated (Fig. 1). However, none of the treatments actually reduced ABG cover from start to finish of the study. Paclobutrazol held ABG cover

Table 5. Cover of annual bluegrass (ABG) taken at spring seedhead production during and after 3 yr of season-long applications of herbicides or growth regulators to creeping bentgrass/ABG maintained on a practice putting green in Lincoln, NE.

Treatment	Applications/year and rate	May 2010†	May 2011	May 2012	May 2013	May 2013
		% cover‡				% change§
Bispyribac-sodium @ 1 oz/acre	8 @ 1 oz/acre	31¶	19 c#	12 abc	23 ab	−24 bc
Bispyribac-sodium @ 2 oz/acre	4 @ 2 oz/acre	32	8 d	3 cd	17 b	−47 c
Cumyluron	2@ 130 oz/acre	30	4 d	1 d	1 c	−95 d
Paclobutrazol	8 @ 8 oz/acre 4 @ 16 oz/acre	32	29 bc	11 bcd	18 b	−43 c
Flurprimidol	5 @ 8 oz/acre 7 @ 16 oz/acre	37	44 a	22 a	30 a	−16 abc
Flurprimidol + trinexapac-ethyl	12 @ 10 oz/acre	32	37 ab	19 ab	32 a	2 ab
Trinexapac-ethyl	12 @ 11 oz/acre	23	31 b	15 ab	24 ab	1 ab
Untreated		29	30 b	18 ab	32 a	13 a

† May 2010 ratings were taken before initiation of treatments.

‡ Annual bluegrass cover was estimated with vertical point quadrat method where a 5- by 5-ft frame laid over the plots with an internal filament grid of 64 intersections. The total number of times ABG was present under each intersection was recorded for each plot and percent cover was calculated.

§ Percent change from the initial ABG cover, calculated as [(ABG cover in final spring rating − ABG cover in initial spring rating)/ABG cover in initial spring rating] × 100.

¶ Means of three replications.

Means within a column followed by the same letter are not significantly different according to Fisher's least significant difference at $P \leq 0.05$.

below that of the untreated throughout the study, with only a 5% increase in ABG cover over the study (Table 4). Similarly, percent cover of ABG in the flurprimidol plots was consistently lower than in the untreated plots, but ABG cover still increased 19% from the initiation to termination of the study (Table 4). Annual bluegrass in the untreated check and the other treatments increased between 45 and 93% during the study in Michigan (Table 4). Both bispyribac-sodium treatments reduced ABG cover by 10 to 16% compared with the untreated check when rated in May of 2010, but had limited effects throughout the rest of the study (Table 4). Similar to the Indiana location, treatments did not cause significant damage to CBG but reduced turf quality when ABG was thinned due to treatments (data not shown).

Cumyluron-treated plots had the lowest AUPPC in Nebraska, followed by paclobutrazol or both of the bispyribac-sodium treatments, and these were the only treatments to reduce AUPPC compared with the untreated in Nebraska (Fig. 1). The same four treatments also reduced ABG cover over the course of the study (Table 5). However, May ratings of ABG were less consistent, with cumyluron and 2.0 oz/acre bispyribac-sodium being the only treatments that reduced ABG cover every May during the study (Table 5). There were no occurrences of significant phytotoxicity to the CBG in Nebraska (data not shown).

Highest ABG cover and poorest ABG control among the three states occurred in Michigan and may be due to a number of factors. More moderate summer weather compared with Nebraska and Indiana likely favored ABG competitiveness and may also have reduced susceptibility of ABG to bispyribac-sodium (McCullough and Hart, 2006) or flurprimidol (Diesburg and Christians, 1989). Furthermore, a stand farther north is more likely to be perennial ABG [*Poa annua* L. ssp. *reptans* (Hausskn.) T. Koyama] than a more southerly stand (Yelverton, 2000). Recent thesis data suggest significant variation in ABG susceptibility to herbicides and perennial subspecies are most tolerant to bispyribac-sodium (Han, 2012). Previous research also indicates differential susceptibility among subspecies to other ABG controls, including rimsulfuron (Wehtje and Walker, 2002) or fenarimol (McElroy et al., 2004).

Turf specialists would rarely recommend application strategies used in this study with usually only one primary active ingredient applied multiple times over many years for fear of developing ABG resistance to any particular product. Though ABG resistance to growth regulators has not been reported, 27 cases of ABG resistance to herbicides, including bispyribac-sodium, have been reported as of this date (Heap, 2014). There were no obvious indications of the development of resistant ABG in any location in this study. However, early indications from a companion genetic study suggests that many of these herbicide or growth regulator treatments affected structure and diversity of ABG populations when sampled 2 or 3 years after study initiation (Brown, 2013).

RECOMMENDATIONS FOR ANNUAL BLUEGRASS CONTROL IN PUTTING GREENS

Our data show effectiveness of treatments varies depending on location, and superintendents may have to experiment to find the most effective treatments for the population of ABG on their golf course. Furthermore, many of our treatments reduced ABG only marginally and thus maximizing cultural practices to control ABG would be important before initiating aggressive use of growth regulators or herbicides. Our data suggest that paclobutrazol should be the first growth regulator that superintendents use as part of a control strategy, followed by flurprimidol. Our data indicate that flurprimidol + trinexapac-ethyl would be less likely to reduce ABG on greens-height turf than paclobutrazol or flurprimidol, and trinexapac-ethyl should not be considered for ABG control on greens-height turf under the conditions of our study. Though bispyribac-sodium is not labeled for putting greens, anecdotal reports indicate superintendents are experimenting with it. If that is the case, four applications of bispyribac-sodium at 2 oz/acre every 2 weeks in August and September would likely be more effective than 1 oz/acre bispyribac-sodium applied every 2 weeks from May through September. To limit chances of ABG resistance to these treatments, superintendents should alternate products in long-term control programs.

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