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Abstract

Annual bluegrass (ABG) (*Poa annua* L.) is a prolific seed producer in the spring on golf courses that in turn decreases aesthetic quality and trueness of ball roll on cool-season putting greens. Proxy (ethephon) applied twice in the spring after green-up is the current industry standard after the loss of Embark (mefluidide) from the turf and ornamental market. However, plant growth regulators including Proxy have been used for years to help suppress ABG seedheads with inconsistent success. The primary objective of this study was to determine if ABG seedhead suppression is improved by adding a late fall application of Proxy to the two traditional spring applications of plant growth regulators at nine locations with diverse environments. A second objective was to determine the importance of including Primo Maxx (trinexapac-ethyl) in fall and spring applications. Adding a late fall application of Proxy prior to the two spring applications (F+S+S) improved control of ABG seedheads over the traditional two spring applications (S+S), but the magnitude of improvement varied among locations.

Abbreviations: ABG, annual bluegrass; AUSCPC, area under seedhead cover progress curve; CBG, creeping bentgrass; DAISA, days after initial spring application; F+S+S, Proxy + Primo Maxx applied once in fall plus twice in spring; GDD, growing degree day; S+S, Proxy + Primo Maxx applied twice in spring.

When treatments were applied F+S+S, the industry standard tank mixture of Proxy + Primo Maxx provided consistent ABG seedhead control and turf quality, similar to Proxy + Fiata (phosphonate + proprietary pigment) and equal to or better than Proxy alone.

1 | INTRODUCTION

Annual bluegrass (ABG) (*Poa annua* L.) is common on cool-season golf courses across the United States. Although ABG is considered a weed in many areas, it is so common and difficult to control that golf course superintendents often manage it as an acceptable turf species (Christians, Patton, & Law, 2017). As primarily a winter annual, ABG is a prolific seed producer in the spring, decreasing aesthetic quality, trueness of ball roll on putting greens, and plant carbohydrate reserves (Cooper, Henderlong, Street, & Karnok, 1987).

Suppressing ABG seedheads has traditionally been attempted with spring applications of either Proxy (ethephon; Bayer Environmental Science) or Embark (mefluidide; PBI/Gordon) plant growth regulators, but Embark recently became unavailable to the turf industry. Two spring applications of Proxy applied shortly after ABG green-up is the standard regime for suppressing ABG seedheads (Askew, 2017; Haguewood, Song, Smeda, Moss, & Xiong, 2013; Inguagiato, Murphy, & Clark, 2010). However, practitioners and researchers indicate inconsistent seedhead suppression, as reviewed by Askew (2017). Growing degree day (GDD) models are used for scheduling applications, and their use improves the consistency of suppression when the initial spring application is made at 50 GDD_{50} or 400 GDD_{32} (Calhoun, 2010; Danneberger, Branham, & Vargas, 1987; Haguewood et al., 2013; Inguagiato et al., 2010). Annual bluegrass is now hypothesized to initiate seedheads (flowers, inflorescences) in late fall or winter, well ahead of their emergence in spring (Askew, 2017). Virginia research demonstrated Proxy applied once in either January or February in addition to two traditionally timed spring plant growth regulator applications of Proxy + Primo Maxx (trinexapac-ethyl; Syngenta) reduced ABG seedheads five to seven times more than the traditionally timed two spring applications alone (Askew, 2017). Van Dyke (2017, 2018) also reported that Proxy applied in late fall in Colorado or Utah with a snow mold application and/or during mid-winter snowmelts provided up to two times improved suppression of ABG seedheads over two traditionally timed spring applications.

It is important to understand whether late fall applications of Proxy consistently suppress ABG seedheads across geographically diverse locations. Therefore, our primary objective was to determine if ABG seedhead suppression can be improved by adding a late fall application of Proxy + Primo Maxx to the two traditional spring applications in seven U.S. states from Virginia to Oregon. Our secondary objective was to determine if the Primo Maxx was important to include with Proxy in fall and spring applications and if it could be replaced by Fiata fungicide (phosphonate + proprietary pigment; Bayer Environmental Science).

2 | NATIONWIDE EVALUATION OF FALL APPLICATIONS FOR SUPPRESSING ANNUAL BLUEGRASS SEEDHEADS

Nine duplicate studies were conducted on mixed stands of creeping bentgrass (*Agrostis stolonifera* L.) (CBG) and ABG at nine U.S. locations, with applications starting in late fall of 2015. Experimental areas were maintained either at putting green height or fairway height on golf courses or at university research centers (Table 1). All experiments were arranged in randomized complete block with three or four replications. Treatments (formulation/1000 ft^2) included an untreated check, the industry standard application of 5 fl oz Proxy 2EC + 0.125 fl oz Primo Maxx 1.5EC applied twice in the spring (S+S), and the following treatments applied once in the fall plus twice in the spring (F+S+S): 5 fl oz Proxy, 5 fl oz Proxy + 0.125 fl oz Primo Maxx, and 5 fl oz Proxy + 4 fl oz Fiata 1.73 L (phosphonate + proprietary pigment). Application details are listed in Table 2. Fall applications were targeted after the final mowing of the year; actual application dates were between 2 and 19 November (Table 2). Growing degree days were calculated daily using local weather stations (McMaster & Wilhelm, 1997) as:

$$GDD_{T_{base}} = \left[\left(T_{max} + T_{min}\right)/2\right] - T_{base}$$

where T_{max} is the daily maximum air temperature, T_{min} is the daily minimum air temperature, and T_{base} is the lowest temperature at which plant growth occurs. Two GDD models were calculated in °F using either 32 °F or 50 °F as T_{base} to characterize environmental conditions at the time of spring treatment. Initial spring applications were targeted at the accumulation of GDD_{50} = 50 (1 February start date) or GDD_{32} = 200–400 (1 January start date). These GDD start dates were earlier than other available models to normalize

accumulations across the wide variety of spring weather conditions across experimental locations.

Data collected throughout the study included visual estimates of percent ABG seedhead cover per plot as well as turf injury (1 = dead, 5 = acceptable, and 9 = no injury) and turf quality (1 = dead, 5 = acceptable quality, and 9 = perfect turf). Seedhead cover measurements were plotted over days after initial spring application through final rating for each location presented as area under seedhead cover progress curve (AUSCPC), similar to other studies on ABG control (Askew, 2017; Reicher et al., 2015; Woosley, Williams, & Powell, 2003). The AUSCPC was calculated as:

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

where X_i is the percentage seedhead cover at the ith observation, t_i is days after the initiation of the study, and n is the number of observations (Woosley et al., 2003). The AUSCPC is similar to area under the disease progress curve (Campbell & Madden, 1990), with lower AUSCPC values indicating a decrease in long-term seedhead cover.

Data were subjected to ANOVA using the GLIMMIX procedure of SAS (SAS 9.4; SAS Institute [2017]), with replication as a random effect. Treatment × location interactions were significant regardless if grouped into subsets by maintenance (green vs. fairway) or locations (east vs. west); thus, data from each location are presented separately. Means were separated using Fisher's protected LSD test ($P \leq .05$). Cover at peak seedhead production (occurring at 29–56 d after initial spring application [DAISA], depending on location), AUSCPC, and turf quality at 30 ± 5 and 56 DAISA are presented.

Core Ideas

- Adding a late fall Proxy (ethephon) application prior to traditional spring Proxy applications improves suppression of annual bluegrass seedheads.
- The magnitude of seedhead suppression from fall + spring Proxy applications can vary by location/population.
- When applied once in fall plus twice in spring, the industry standard mixture of Proxy + Primo Maxx as well as Proxy + Fiata provides consistent seedhead control and improved turf quality over Proxy alone.

3 | A LATE FALL APPLICATION IMPROVES CONTROL OF ANNUAL BLUEGRASS SEEDHEADS AND TURF QUALITY

The current industry standard of Proxy + Primo Maxx applied S+S had an average of 25% less seedhead coverage than the untreated at peak production at eight of nine locations (11–51% fewer seedheads, depending on location) (Figure 1). Researchers at most sites made the initial spring application within recommended application timing of 50 GDD_{50} (Danneberger et al., 1987), which may have maximized suppression from Proxy + Primo applied S+S. The most dramatic reductions in seedhead cover occurred in locations managed as greens at <0.156 inches (Connecticut; Fairfax, Virginia; Michigan; Utah; and Oregon) (Figure 1). There was no difference in peak seedhead coverage between the untreated and Proxy + Primo Maxx applied S+S at the Nebraska 1-yr-old site. Practitioners often report poor seedhead control from Proxy on newly renovated or summer-damaged sites with relatively recent colonization of annual bluegrass. Adding a fall application of Proxy + Primo Maxx (F+S+S) decreased seedhead cover at peak production another 22% on average (range, 6–30%) at five of the nine locations compared with Proxy + Primo Maxx applied S+S. There were substantial differences in magnitude of decreased peak seedhead cover among locations, with Proxy + Primo Maxx applied F+S+S, causing up to 30% less seedhead cover than Proxy + Primo Maxx S+S in the Fairfax, Virginia and Nebraska (3-yr-old) sites and numerical reductions (no statistical differences) in Blacksburg, Virginia; Utah; Nebraska (1-yr-old); and Oregon (Figure 1). Similar trends occurred in AUSCPC, where Proxy + Primo Maxx applied S+S decreased AUSCPC compared with the untreated at all locations, and adding the fall application of Proxy + Primo Maxx further decreased AUSCPC at six of the nine locations (Figure 2). These data largely reflect personal observations on golf courses where adding a fall application of Proxy usually improves seedhead suppression, but the magnitude of that suppression is variable. Part of this variability is likely due to inconsistency among populations of annual bluegrass and could also be due to difficulty in judging reductions in annual bluegrass seedheads for practitioners. Therefore, leaving a small, untreated plot may help practitioners accurately observe the performance of seedhead-suppressing growth regulators.

Turf quality responses inversely followed seedhead cover responses, with the untreated check plots rated as lowest quality at 30 and 56 DAISA (Figures 3 and 4). Turf quality from Proxy + Primo Maxx applied F+S+S was equal to or better than that of Proxy + Primo Maxx applied S+S at all locations at 30 and 56 DAISA. Reduced seedhead cover also led to improved turf quality in other reports (Askew, 2017; Haguewood et al., 2013; Van Dyke, 2017).

TABLE 1 Location description and management of sites evaluating fall and spring applications for controlling seedheads of annual bluegrass

	Connecticut	Blacksburg, VA	Fairfax, VA	Michigan	Indiana	Nebraska, 1 yr old	Nebraska, 3 yr old	Utah	Oregon
Location	Plant Science Research and Education Facility	Glade Road Research Facility	International Country Club	Hancock Turfgrass Research Center	W.H. Daniel Turfgrass Research Center	John Seaton Anderson Turfgrass Research Center	John Seaton Anderson Turfgrass Research Center	Forest Dale Golf Course	Lewis-Brown Horticulture Farm
City	Storrs	Blacksburg	Fairfax	East Lansing	West Lafayette	Mead	Mead	Salt Lake City	Corvallis
Soil type	Paxton fine sandy loam	Groseclose silt loam	USGA sand mix	Aubbeenaubbee-Capac sandy loam	Starks-Fincastle silt loam	Tomek silt loam	Tomek silt loam	native clay pushup with sand topdressing layer	100% USGA specification sand
Age of stand, yr	1	>10	>20	>25	5	1	3	>40	7
Species composition[a]	66% ABG/34% CBG	30% ABG/70% CBG	60% ABG/40% CBG	100% ABG	25% ABG/75% CBG/	90-100% ABG	50% ABG/50% CBG	99% ABG	99% ABG
Mowing height, inches	0.125	0.5	0.125	0.125	0.5	0.25	0.25	0.156/0.135	0.14/0.125
N applied during study, lb N per 1000 ft^2	1.4	0.6	0.9	1.6	1.55	1.0	1.0	2	1.8
Spray volume, gal M^{-1}	2	2	2	1.5	2	2	2	2	2
PSI	40	40	40	40	30	35	35	40	35
Plot size	3 × 6 ft	6 × 6 ft	3 × 6 ft	4 × 10 ft	5 × 5 ft	5 × 5 ft	5 × 5 ft	4 × 6 ft	5 × 5 ft
Replications	4	3	3	4	4	3	3	4	3

[a] ABG, annual bluegrass; CBG, creeping bentgrass.

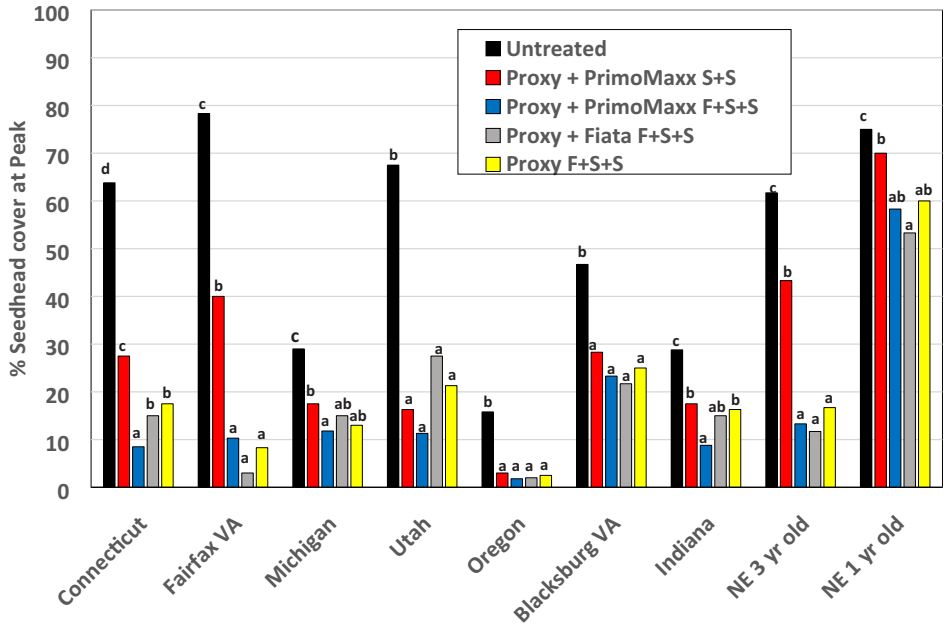

FIGURE 1 Annual bluegrass seedhead percent cover at peak seedhead production in nine locations across seven states. Treatments included untreated check, Proxy + Primo Maxx applied twice in spring (S+S), Proxy + Primo Maxx applied once in fall plus twice in spring (F+S+S), Proxy + Fiata applied F+S+S, and Proxy applied F+S+S. Sites were maintained under either greens height at <0.156 inches (Connecticut; Fairfax, Virginia; Michigan; Utah; and Oregon) or fairway height at >0.25 inches (Blacksburg, Virginia; Indiana; and Nebraska 3- and 1-yr-old). Treatment means with a different letter are significantly different ($P < .05$) within each location.

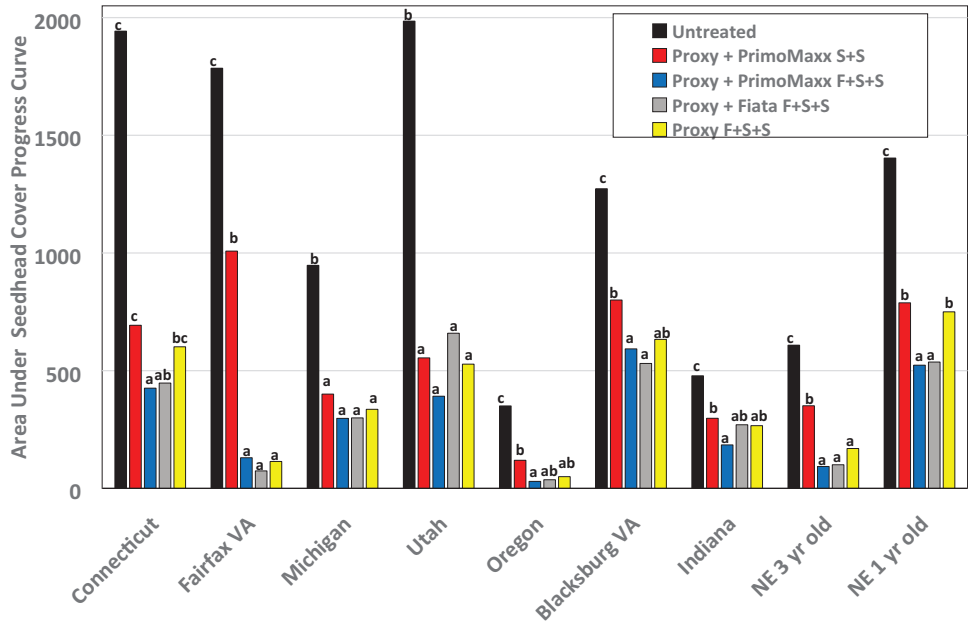

FIGURE 2 Area under seedhead cover progress curve (AUSCPC) calculated from all seedhead cover ratings from initial spring application to termination of study at nine locations in seven states. Treatments included untreated check, Proxy + Primo Maxx applied twice in spring (S+S), Proxy + Primo Maxx applied once in fall plus twice in spring (F+S+S), Proxy + Fiata applied F+S+S, and Proxy applied F+S+S. Sites were maintained under either greens height at <0.156 inches (Connecticut; Fairfax, Virginia; Michigan; Utah; and Oregon) or fairway height at >0.25 inches (Blacksburg, Virginia; Indiana; and Nebraska 3- and 1-yr-old). Treatment means with a different letter are significantly different ($P < .05$) within each location

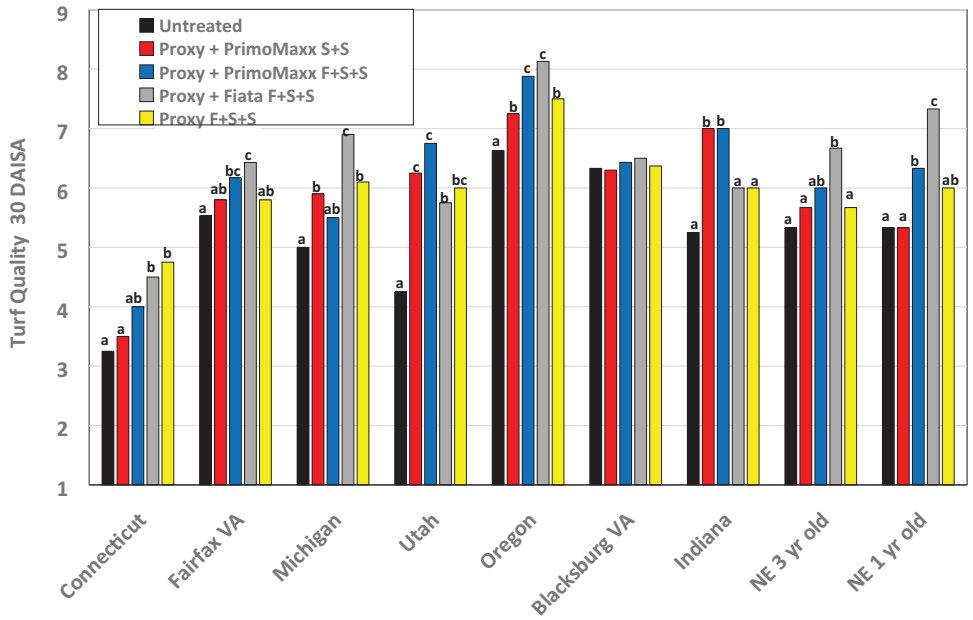

FIGURE 3 Turf quality rated 30 ± 5 days after initial spring application (DAISA) in nine locations reporting across eight states. Treatments included untreated check, Proxy + Primo Maxx applied twice in spring (S+S), Proxy + Primo Maxx applied once in fall plus twice in spring (F+S+S), Proxy + Fiata applied F+S+S, and Proxy applied F+S+S. Sites were maintained under either greens height at <0.156 inches (Connecticut; Fairfax, Virginia; Michigan; Utah; and Oregon) or fairway height at >0.25 inches (Blacksburg, Virginia; Indiana; and Nebraska 3- and 1-yr-old). Treatment means with a different letter are significantly different ($P < .05$) within each location

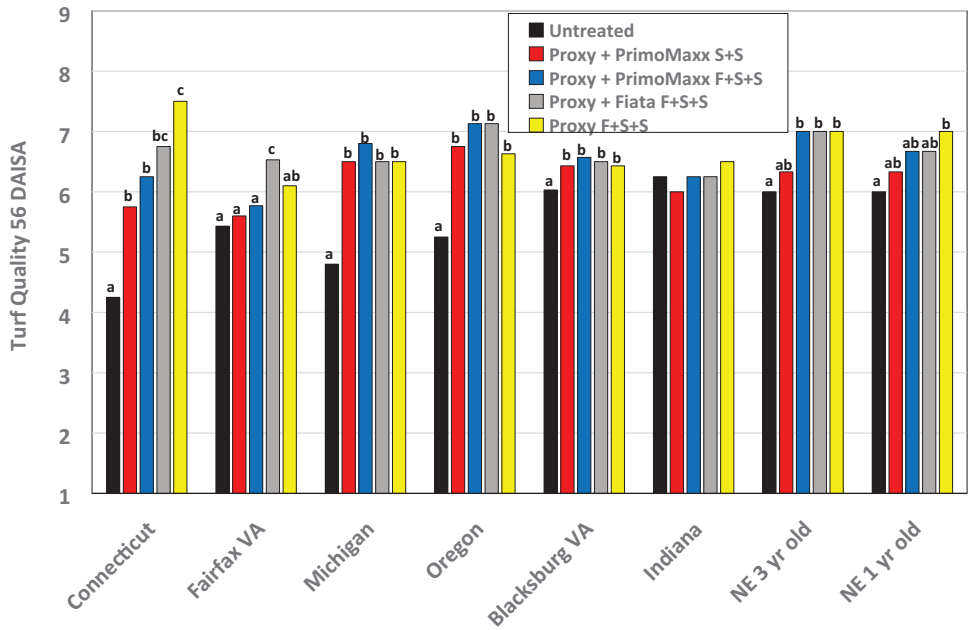

FIGURE 4 Turf quality rated 56 days after initial spring application (DAISA) in eight locations reporting across six states. Treatments included untreated check, Proxy + Primo Maxx applied twice in spring (S+S), Proxy + Primo Maxx applied once in fall plus twice in spring (F+S+S), Proxy + Fiata applied F+S+S, and Proxy applied F+S+S. Sites were maintained under either greens height at <0.156 inches (Connecticut; Fairfax, Virginia; Michigan; Utah; and Oregon) or fairway height at >0.25 inches (Blacksburg, Virginia; Indiana; and Nebraska 3- and 1-yr-old). Treatment means with a different letter are significantly different ($P < .05$) within each location

TABLE 2 Dates and growing degree day accumulations (GDD_{32} and GDD_{50}) for applications evaluating fall 2015 and spring 2016 applications for controlling seedheads of annual bluegrass

	Connecticut	Blacksburg, VA	Fairfax, VA	Michigan	Indiana	Nebraska, 1 yr old	Nebraska, 3 yr old	Utah	Oregon
Fall application date	9 Nov.	13 Nov.	11 Nov.	2 Nov.	8 Nov.	13 Nov.	13 Nov.	19 Nov.	4 Nov.
Initial spring application date	13 Mar.	12 Mar.	16 Mar.	1 Apr.	14 Mar.	7 Mar.	7 Mar.	17 Mar.	3 Mar.
GDD_{32} (1 Jan. start date)[a]	350	400	604[b]	408[b]	419[b]	243	243	567[b]	814[b]
GDD_{50} (1 or 15 Feb. start date)[a]	30	42	75[b]	23	45	49	49	37	16
Second spring application	30 Mar.	8 Apr.	14 Apr.	25 Apr.	12 Apr.	5 Apr.	5 Apr.	18 Apr.	30 Mar.
GDD_{32} (1 Jan. start date)	529	877	1132	727	820	667	667	1164	1254
GDD_{50} (1 or 15 Feb. start date)	32	123	183	79	80	93	93	148	35

[a]Target application timing was 200–400 GDD_{32} or 50 GDD_{50}. [b]An application was made outside the targeted application window. For coastal and western climates, GDD accumulate more rapidly at GDD_{32}.

4 | COMBINING PRIMO MAXX OR FIATA WITH LATE FALL APPLICATION OF PROXY PRIOR TO TWO SPRING APPLICATIONS

Including Primo Maxx or Fiata with Proxy applied F+S+S had little effect on seedhead suppression compared with Proxy applied F+S+S. Primo Maxx plus Proxy applied F+S+S reduced peak seedhead cover in Connecticut and Indiana (Figure 1) and reduced AUSCPC in Connecticut and Nebraska 1-yr-old sites (Figure 2) compared with Proxy applied F+S+S. Including Fiata with Proxy applied F+S+S reduced AUSCPC at the Nebraska 1-yr-old site (Figure 2) over Proxy applied F+S+S. Including Primo Maxx with Proxy applied F+S+S improved turf quality at 30 DAISA in Oregon and Indiana (Figure 3) but decreased turf quality at 56 DAISA in Connecticut (Figure 4) compared with Proxy applied F+S+S. Fiata + Proxy applied F+S+S improved turf quality at 30 DAISA at the Fairfax, VA; Michigan; Oregon; Indiana; Nebraska 1-yr-old; and Nebraska 3-yr-old sites (Figure 3) and at 56 DAISA in Fairfax, VA (Figure 4) compared with Proxy applied F+S+S.

There were few differences in performance when comparing Proxy + Fiata applied F+S+S and Proxy + Primo Maxx applied F+S+S directly because these treatments affected peak seadhead cover and AUSCPC similarly at all locations except in Connecticut, where Proxy + Fiata applied F+S+S reduced peak seedhead cover over Proxy + Primo Maxx applied F+S+S by 6.5% (Figure 1). Proxy + Fiata applied F+S+S and Proxy + Primo Maxx applied F+S+S affected turf quality similarly, except where Fiata improved turf quality over Primo Maxx in Michigan and Nebraska 1-yr-old at 30 DAISA and in Fairfax, VA, at 56 DAISA.

Similar to other studies with fall and winter applications (Askew, 2017; Van Dyke, 2017, 2018), turf injury was rare from any treatment and was short-lived if it occurred. Proxy + Fiata caused minor injury to CBG after the fall application in Fairfax, VA (data not shown), whereas Proxy + Primo Maxx applied in fall caused injury in Michigan and Utah (data not shown). Similar to Askew (2017) and Haguewood et al. (2013), Proxy alone did not cause turf injury regardless of application timing. Although Dernoeden and Pigati (2009) reported crown elevation and scalping of CBG after Proxy was applied in mid-summer heat, neither was seen in these studies.

5 | PRACTICAL RECOMMENDATIONS FOR CONTROLLING ANNUAL BLUEGRASS SEEDHEADS

Adding a late fall application of Proxy to the standard two spring applications improved suppression of annual bluegrass seedheads over the traditional two spring applications across

diverse locations and maintenance regimes. The magnitude of improvement in seedhead control varied depending on geography and, likely, on annual bluegrass populations. Judging suppression of annual bluegrass seedheads by practitioners can be improved by including small untreated areas when making applications. Further research and practical experience with alternate application timings, number of applications, and application rates may further improve control in environments where ABG seedhead control is troublesome. This is somewhat expected because vernalization and photoperiod requirements to initiate ABG flowering are variable across populations and thus are expected to differ across locations (Johnson & White, 1997a, 1997b). The differing level of response to Proxy applications is also not unexpected given the differential responses to herbicides and the growth regulator Trimmit (paclobutrazol) at different locations (Patton et al., 2019; Reicher et al., 2015).

Flexibility in the fall application timing likely exists given the results from November applications in the current study, pre-snow and post-snowmelt applications in Utah and Colorado (Van Dyke, 2017), and January or February applications in Virginia (Askew, 2017). Furthermore, initial spring applications in some locations in our current study were made later than recommended by GDD models, yet seedhead control was still acceptable (Table 2; Figure 1). This suggests that spring applications may be more flexible as long as application of Proxy was made the previous fall or winter. Adding Proxy to the snow mold application just prior to snowfall is labor efficient, has not resulted in tank-mix incompatibilities to date (Van Dyke, 2018), and has not affected snow mold control (Bayer, unpublished internal data). The industry standard tank mixture of Proxy + Primo Maxx applied F+S+S provided consistent seedhead control and turf quality with no phytotoxicity following late fall or early spring applications in our study. However, superintendent use in the field has caused occasional turf injury with the late fall or early spring applications prior to heavy frost, as also mentioned by Askew (2017), especially on nontarget sites like higher mowed collars and rough surrounding greens. Therefore, golf course superintendents should omit Primo Maxx from the fall and first spring application or replace it with Fiata if discoloration occurred with past applications or if heavy frost is expected shortly after application.

CONFLICT OF INTEREST

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