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Zoysiagrass and weed response to herbicides during post-dormancy transition

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Abstract

Winter annual weeds begin to germinate as zoysiagrass enters winter dormancy in autumn. These weeds can suppress zoysiagrass shoot development the following spring through competition for sunlight, moisture, and nutrients. Previous research involving winter annual weed control in dormant turfgrass has been conducted primarily on bermudagrass, but less is known about how various herbicides used for this purpose will influence zoysiagrass after dormancy transition. Two field studies were conducted over 7 site-years between 2016 and 2020 to evaluate 17 herbicide treatments that are typically marketed for broadleaf weed control in spring and 18 herbicide treatments that are typically marketed for annual bluegrass control during winter for their effects on a variety of weeds and semidormant 'Meyer' and dormant 'Zeon' zoysiagrass, respectively. Glufosinate, glyphosate + simazine, and indaziflam + simazine controlled Persian speedwell by more than 90% and control was significantly greater with auxin-type and other herbicide combinations. Dandelion and Persian speedwell were better controlled with a combination of simazine and glyphosate than when glyphosate was applied alone. Glufosinate controlled dandelion, hairy bittercress, and Persian speedwell more effectively than glyphosate. In Meyer zoysiagrass, glyphosate and glufosinate controlled annual bluegrass equivalently, whereas in Zeon zoysiagrass, glyphosate controlled annual bluegrass better than glufosinate did. Foramsulfuron or treatments that contained simazine resulted in >90% control of annual bluegrass. A flumioxazin admixture with diquat, glufosinate, or glyphosate improved annual bluegrass control. Herbicide treatments that contain diquat, glufosinate, glyphosate, and metsulfuron alone or in a tank-mix should not be applied to Meyer zoysiagrass with 5% visual green turf cover due to high injury potential. In both studies, glufosinate was more injurious to Meyer and Zeon zoysiagrass than glyphosate. Overall, several herbicides that control annual bluegrass or broadleaf weeds can be safely applied to Zeon zoysiagrass during dormancy or Meyer zoysiagrass during post-dormancy transition.

Introduction

In the United States, 'Meyer' and 'Zeon' zoysiagrass are the most widely used zoysiagrass species, with 78% of total zoysiagrass planted on golf courses reported in transition climatic zones (Patton 2009; Patton et al. 2017b). Adoption of zoysiagrass has increased in the United States as an alternative to bermudagrass, which has suffered from winter kill since the 1970s (Patton et al. 2017b). Zoysiagrass (*Zoysia* spp.) winter dormancy coincides with the peak growth of winter annual weeds (Bingham et al. 1969; Johnson 1977, 1980). Winter annual weeds can disrupt the aesthetic value of zoysiagrass turf if left uncontrolled and they can potentially slow the zoysiagrass post-dormancy transition by competing for space, water, and nutrients (Hall and Carey 1992; Johnson 1980). Both preemergence and postemergence herbicides are often used to control winter annual weeds in dormant turfgrass (Johnson and Carrow 1999). Such herbicides have been extensively investigated with bermudagrass (*Cynodon* spp.) (Johnson 1976, 1984; Johnson and Ware 1978; Toler et al. 2007), but few studies have reported their use in zoysiagrass. Zoysiagrass and bermudagrass respond differently to herbicides, and interspecies variations need to be considered when developing weed control recommendations (Johnson 1987; Patton et al. 2017a; Song et al. 2013). By investigating the literature on herbicides used in bermudagrass and comparing herbicide label recommendations for use in both bermudagrass and zoysiagrass, one can discover several viable herbicide options for weed control in dormant or semidormant zoysiagrass.

Annual bluegrass has been reported as one of the most common and troublesome weeds of turf, and warm-season turfgrass systems that include dormant turfgrass management are no exception (Beard et al. 1978; Christians et al. 2011; Van Wychen 2020). Postemergence herbicides are commonly needed in the spring or winter to control annual bluegrass on dormant turfgrass due to the weed's long germination period and ability to outlast the residual control period for some preemergence herbicides (Johnson and Burns 1985; McElroy et al. 2004). Winter broadleaf weeds are most commonly controlled using herbicides that mimic growth hormones (i.e., synthetic auxin herbicides). Two-way and three-way mixtures of 2,4-D, dicamba, triclopyr, and MCPP have long been the standard for winter broadleaf weed control in bermudagrass (Johnson 1975a). However, control of certain weeds such as corn speedwell (*Veronica arvensis* L.), parsley-piert (*Aphanes arvensis* L.), and henbit (*Lamium amplexicaule* L.) with these herbicides has been inconsistent when they were investigated in bermudagrass and the herbicides have also injured dormant and semidormant bermudagrass (Derr and Serensits 2016; Johnson 1980). A large selection of herbicides other than hormone mimics, including acetolactate synthase inhibitors, photosystem II inhibitors, amino acid inhibitors, and cell wall biosynthesis inhibitors are routinely employed to control specific weed populations in dormant turfgrass (Brosnan et al. 2012b; Johnson 1975b, 1984; Reed et al. 2015; Toler et al. 2007).

Selective herbicides such as simazine, a photosystem II inhibitor, control annual bluegrass and broadleaf weeds both before and after they emerge (Johnson 1982). Toler et al. (2007) found that simazine controlled annual bluegrass by 86% and 79% in dormant bermudagrass when applied in December and February, respectively. Simazine also controls corn speedwell and other broadleaf weeds (Johnson 1982). Toler et al. (2007) reported that the acetolactate synthase inhibitors, including foramsulfuron, flazasulfuron, rimsulfuron, and trifloxysulfuron, controlled annual bluegrass by more than 86% in bermudagrass. Many turfgrass managers in the transition zone of the United States have adopted the strategy of applying nonselective herbicides such as glyphosate, diquat, and glufosinate in winter, which is an effective method to control a broad spectrum of grassy and broadleaf weeds in dormant bermudagrass (Johnson 1976, 1980; Johnson and Ware 1978; Velsor et al. 1989). A few researchers have also reported the use of these nonselective herbicides in dormant or semidormant zoysiagrass (Hoyle and Reeves 2017; Rimi et al. 2012; Velsor et al. 1989; Xiong et al. 2013). A single glyphosate application has been shown to control henbit, corn speedwell, and common chickweed (*Stellaria media* L.) more effectively than a three-way mixture of synthetic auxin herbicides in dormant bermudagrass turf (Johnson 1976). Xiong et al. (2013) reported that glyphosate and glufosinate both effectively controlled annual bluegrass and mouse-ear chickweed (*Cerastium vulgatum* Hartm.) in dormant zoysiagrass.

Research has indicated that glyphosate and glufosinate applied to dormant zoysiagrass will not delay post-dormancy transition (Hoyle and Reeves 2017; Rimi et al. 2012; Velsor et al. 1989; Xiong et al. 2013). However, these herbicides may injure zoysiagrass if green tissue is abundant during treatment (Rimi et al. 2012; Velsor et al. 1989; Xiong et al. 2013). Tank mixing nonselective herbicides with residual products such as flumioxazin, oxadiazon, and indaziflam is a means of controlling existing winter annual weeds while also preventing subsequent summer annual weeds (Brecke et al. 2010; Brosnan et al. 2012b; Reed et al. 2015). Some of the herbicide combinations mentioned above can be safely applied to actively growing turfgrass, but others must be applied to dormant turfgrass due to excessive injury potential (Brecke et al. 2010; Johnson and Carrow 1999; Reed et al. 2015). Herbicides such as flumioxazin, indaziflam, simazine, diquat, flazasulfuron, foramsulfuron, trifloxysulfuron, foramsulfuron, sulfentrazone, 2,4-D + dicamba + MCPP + carfentrazone, 2,4-D + 2,4-DP + dicamba + carfentrazone, MCPA + dicamba + triclopyr, and 2,4-D + dicamba + fluroxypyr have not been examined for weed-control efficacy and zoysiagrass response prior to or during post-dormancy transition.

Since the majority of research involving winter annual weed control in turfgrass has been conducted on bermudagrass, more information is needed to elucidate zoysiagrass response to herbicides used for this purpose. Therefore, this study was designed to 1) evaluate Meyer zoysiagrass during its post-dormancy transition for its tolerance to several herbicides that are traditionally used to target broadleaf weeds for winter weed control, and 2) assess several herbicide rates and mixtures when applied to dormant turf for their ability to control annual bluegrass and the response of dormant 'Zeon' zoysiagrass.

Materials and Methods

Effect of Broadleaf Weed Control Products on Weeds and Semidormant Meyer Zoysiagrass

Five field trials were conducted at the Virginia Tech Turfgrass Research Center (TRC) in Blacksburg, VA (37.21°N, 80.41°W), to evaluate broadleaf weed control and semidormant zoysiagrass response to 17 herbicides during winter and spring of 2017, 2018, and 2020. On March 27, 2017, at 250 growing degree days at base 5 C (GDD_{5C}), a field trial was initiated at the TRC on a mixed stand of broadleaf weeds with no desirable turfgrass. An additional trial was established concurrently on adjacent, weed-free Meyer zoysiagrass to assess turfgrass tolerance. On March 17, 2018, at 168 GDD_{5C}, these two trials were repeated at adjacent locations. Because the tolerance trial from 2017 was confounded by winterkill and large-patch disease caused by *Rhizoctonia solani* Kuhn, this study was repeated on March 18, 2020, at 156 GDD_{5C} on a uniform area of Meyer zoysiagrass. Weeds that were evaluated at two or more sites included annual bluegrass, common chickweed, dandelion, hairy bittercress, and Persian speedwell. Weedy plots contained an average of 10% common chickweed, 7% dandelion, 10% hairy bittercress, and 40% Persian speedwell at trial initiation. All weeds were mature when treated. Soil for all trials was a Groseclose urban land complex (clayey, mixed, mesic, Typic Hapludalf), pH 5.4 ± 0.2 and 3.5% ± 0.3% organic matter, depending on the year. The weed control trials were mown with a rotary mower at 3.8 cm twice weekly during active growth with clippings returned. No irrigation, fertilizer, or pesticides were applied to any trial site within 1 mo of herbicide treatments. The zoysiagrass tolerance trials were mown with a reel mower at 1.3 cm twice weekly during active growth with clippings being returned. On average, plots had between 5% ± 3% visual green zoysiagrass cover and 114 ± 30 green leaves dm^{-2} when herbicides were applied with the majority of these leaves located below the upper canopy (Figure 1). Zoysiagrass green leaf counts were collected by counting all green leaves or leaf parts present within a 10-cm by 10-cm area, at randomly selected locations in each plot. The treatment timing for these studies was intended to imitate a spring herbicide application to a semidormant (but actively greening) zoysiagrass when broadleaf weeds are most commonly targeted by turf managers using selective herbicides.

Experiments were implemented as randomized complete blocks with four replicates, and plots were 1.7 m^2. Treatments were applied with a CO_2-pressurized boom sprayer equipped with TTI 11004 nozzles (TeeJet Technologies, Springfield, IL) calibrated to deliver 280 L ha^{-1}. Herbicide common names, trade names, manufacturers, and rates are listed in Table 1. Data

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Table 1. Herbicides used in weed control studies of semidormant 'Meyer' zoysiagrass.[a]

Common chemical name	Product name	Manufacturer	Rate
			g ai ha^{-1}
2,4-D + dicamba + fluroxypyr	Escalade 2	Nufarm Americas Inc, Burr Ridge, IL	1,680 + 210 + 210
MCPA + dicamba + triclopyr	Cool Power	Nufarm Americas Inc, Alsip, IL	147 + 1,470 +147
2,4-D + dicamba + MCPP + carfentrazone	Speedzone	PBI Gordon Corporation, Kansas City, MO	857 + 269 + 78.4 + 8.0
2,4-D + 2,4-DP + dicamba + carfentrazone	Speedzone Southern	PBI Gordon Corporation, Kansas City, MO	286 + 168 + 28 + 2.4
Diquat	Reward	Syngenta Crop Protection, LLC; Greensboro, NC	560
Florasulam[b]	Defendor	Corteva Agroscience, LLC, Indianapolis, IN	14.7
Foramsulfuron[c]	Revolver	Bayer Environmental Science, Research Triangle Park, NC	28.2
Foramsulfuron + florasulam[c]	Defendor; Revolver	Corteva Agroscience, LLC, Indianapolis, IN; Bayer Environmental Science, Research Triangle Park, NC	28.2 + 14.7
Foramsulfuron + halosulfuron + thiencarbazone[b,c]	Tribute Total	Bayer Environmental Science, Research Triangle Park, NC	28.2 + 43.1 + 13.9
Glufosinate	Finale	Bayer Environmental Science, Research Triangle Park, NC	1,680
Glyphosate	Roundup Pro Conc.	Monsanto Company, St. Louis, MO	520
Glyphosate + simazine	Roundup Pro Conc.; Princep Liquid	Monsanto Company, St. Louis, MO 63167; Syngenta Crop Protection, LLC, Greensboro, NC	520 + 2,240
Indaziflam[d]	Specticle Flo	Bayer Environmental Science, Research Triangle Park, NC	32.6
Indaziflam + simazine[d]	Specticle Flo; Princep Liquid	Bayer Environmental Science, Research Triangle Park, NC; Syngenta Crop Protection, LLC, Greensboro, NC	32.6 + 2,240
Metsulfuron[b]	MSM Turf	FarmSaver.com, LLC, Raleigh, NC	21.0
Metsulfuron + sulfentrazone	Blindside	FMC Corporation, Philadelphia, PA	42.0 + 420
Sulfentrazone	Dismiss	FMC Corporation, Philadelphia, PA	280

[a]Studies were conducted at the Virginia Tech Turfgrass Research Center, Blacksburg, VA, in 2017, 2018, and 2020.
[b]A nonionic surfactant at 0.25% v/v was added.
[c]Methylated seed oil at 1% v/v and ammonium sulfate (100% soluble granule) at 1,680 g ha^{-1} were added to the treatment.
[d]Methylated seed oil at 1% v/v was added.

Figure 1. Herbicides were applied to 'Meyer' zoysiagrass with 5% ± 3% visual green zoysiagrass cover and 114 ± 30 green leaves dm^{-2} to assess the effect of broadleaf weed control products on weeds and semidormant Meyer zoysiagrass.

consisted of weed control, zoysiagrass green cover, zoysiagrass injury, and normalized difference vegetative index (NDVI) at 0, 7, 14, 21, 28, 42, 56, and 70 d after treatment (DAT). Weed control was assessed visually on a 0% to 100% scale, where 0% indicates that plots had equivalent green weed vegetation compared with the nontreated plots, and 100% indicates all green vegetation of the target weed was eliminated. Zoysiagrass green cover was assessed as a visually estimated percentage of plot area. Zoysiagrass injury was assessed similar to weed control on a 0% to 100% scale based on visually estimated loss of green vegetation where 30% or greater injury was considered unacceptable. Measurements of NDVI were collected using a Crop Circle ACS 210 (Holland Scientific Inc., Lincoln, NE) active crop sensor affixed 43 cm above the turf that collected 50 ± 5 readings per plot scanning a 0.5-m by 1.6-m area of turf canopy in the center of each plot.

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Data Analysis

Zoysiagrass green cover, NDVI, and turf injury measurements over time were converted to the area under progress curve (AUPC) using the following equation:

$$\partial = \sum_{i=1}^{ni-1}\left(\frac{\left(y_i + y_{(i-1)}\right)}{2}\left(t_{(i+1)} - t_{(i)}\right)\right) \quad [1]$$

where ∂ is the AUPC, i is the ordered sampling date, ni is the number of sampling dates, y is the response (turf green cover, NDVI, or turf injury), and t is the time in days. The AUPC was then converted to the average per day by dividing by the number of days spanned by the assessment period. Campbell and Madden (1990) applied this equation to disease epidemiology, and Askew et al. (2013) and Brewer et al. (2017) used it for weediness over time in a turfgrass comparison study. The AUPC is useful in situations where long durations of plant injury and recovery are assessed by repeated measures and offers a better comparison between treatments when the severity and duration of the measured response are variable. Such variable temporal responses are common with herbicide-induced injury caused by disparate herbicide modes of action. The AUPC per day (AUPC d^{-1}) data were subjected to ANOVA with sums of squares partitioned to reflect year, treatment, replication, and year by treatment effects. The four included years were considered a single random variable, and mean square error associated with treatment effects were tested with the mean square associated with year by treatment effect (McIntosh 1983). For weed control, selected assessment dates that represented treatment effects were analyzed separately. Common chickweed and hairy bittercress control data from 28 DAT were analyzed to separate treatment responses before these weeds senesced due to summer heat. Annual bluegrass, dandelion, and Persian speedwell control data were analyzed at the study conclusion, 56 DAT. Data were presented separately by year if a significant year-by-treatment interaction was detected ($P < 0.05$), otherwise data were pooled over years. Appropriate interactions or main effects were subjected to Fisher's protected LSD test at $\alpha = 0.05$ to compare means.

Effect of Herbicides on Annual Bluegrass and Dormant Zeon Zoysiagrass

Field trials were established in 2016, 2017, 2018, and 2020 to investigate annual bluegrass control and Zeon zoysiagrass response to 18 herbicide treatments. The first three studies were conducted at the Westlake Golf Course (Westlake) in Hardy, VA (37.13°N, 79.72°W), and the 2020 study was conducted at the Glade Road Research Facility (GRRF) in Blacksburg, VA (37.23°N, 80.44°W). Research sites had no reported history of annual bluegrass resistance to herbicides in Groups 2, 9, 10, and 14 (as categorized by the Weed Science Society of America) evaluated in the study. The sites and zoysiagrass variety were chosen based on availability of uniform weed populations and popularity of Zeon zoysiagrass. Herbicides were initially applied on March 1, 2016; February 17, 2017; March 16, 2018; and February 26, 2020, at 30, 100, 164, and 87 GDD_{5C}, respectively. Zoysiagrass was mown to 1.3 cm using a reel mower three times per week during active growth with clipping returned in all years. Soil at Westlake was a Clifford fine sandy loam (fine, kaolinitic, mesic Typic Kanhapludult), pH 6.3, and with 3.2% organic matter. At the GRRF, soil was a complex of Duffield silt loam (fine-loamy, mixed, active, mesic, Ultic Hapludalf) and Ernest silt loam (fine-loamy, mixed, superactive, mesic Aquic Fragiudult), pH 6.8, and with 3.5% organic matter. All sites had a natural annual bluegrass infestation with 30% to 50% coverage of 10- to 20-tiller plants at Westlake and 3% to 5% coverage of 5- to 10-tiller plants at the GRRF. Zoysiagrass had fewer than 20 subcanopy green or partially green leaves dm^{-2} and no visible green cover at application for all sites (Figure 2). No pesticides, irrigation, or fertilizers were applied to any experimental sites while the experiment was in progress.

Studies were arranged as randomized complete block designs with three replications. Plots at Westlake were 1.8 by 3.6 m, and plots at the GRRF were 1.2 by 1.8 m. Herbicide treatments, trade names, manufacturers, and rates applied, are listed in Table 2. Treatments were applied at 280 L ha^{-1} with the same equipment as the aforementioned broadleaf products study. Annual bluegrass cover and control, zoysiagrass green cover and injury, and NDVI data were collected at 0, 7, 14, 21, 28, 42, 56, 70, and 84 DAT using methods previously described in the broadleaf-products study. In 2018, zoysiagrass response data was confounded by winterkill and disease and were omitted from the analysis.

Data Analysis

Annual bluegrass cover, annual bluegrass control, zoysiagrass green cover, NDVI, and turf injury measurements over time were converted to AUPC per day using the same formula and parameters as mentioned previously. Maximum observed turfgrass injury was also recorded as the highest injury data recorded on any assessment date. A separate analysis of annual bluegrass cover and control was also conducted for the final rating at 84 DAT. These data were subjected to ANOVA with sums of squares partitioned to reflect the year, treatment, replication, and year-by-treatment effects. Mean square tests and mean separations were conducted as previously described.

Results and Discussion

Effect of Broadleaf Weed Control Products on Weeds and Semidormant Meyer Zoysiagrass

The interaction of year by herbicide was not significant for common chickweed ($P = 0.6428$) and hairy bittercress ($P = 0.1020$) control 28 DAT or for Persian speedwell ($P = 0.2356$) and annual bluegrass ($P = 0.1010$) control 56 DAT (Table 3). The main effect of herbicide was significant for all four of these weeds ($P < 0.0001$); therefore, data were pooled over years. The interaction of year by herbicide treatment was significant for dandelion control 56 DAT ($P < 0.0001$); therefore, data were presented separately for the 2 yr this weed was evaluated.

Diquat, florasulam, foramsulfuron, glufosinate, glyphosate, simazine, and metsulfuron applied alone or in mixtures with other herbicides controlled common chickweed by 80% at 28 DAT (Table 3). Auxin-type herbicides in various combinations and sulfentrazone did not control common chickweed more than 74% (Table 3). Slightly reduced control by auxin-type herbicides and sulfentrazone has been reported by other researchers when herbicides are applied during cold temperatures to blooming plants (Derr and Serensits 2016; Raudenbush and Keeley 2014). Glyphosate controlled hairy bittercress by 83% at 28 DAT, and less than diquat or glufosinate (>95% control), but equivalent to most other herbicides (Table 3). However, florasulam, foramsulfuron, and sulfentrazone controlled hairy bittercress by 70% or less (Table 3). Previous research using container-grown crops has

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Table 2. Herbicides applied to dormant 'Zeon' zoysiagrass.[a]

Common chemical name	Product name	Manufacturer	Rate
			g ai ha^{-1}
Diquat	Reward	Syngenta Crop Protection, LLC; Greensboro, NC	280
Diquat	Reward	Syngenta Crop Protection, LLC; Greensboro, NC	560
Diquat + flumioxazin[b]	Reward; SureGaurd	Syngenta Crop Protection, LLC; Greensboro, NC; Valent USA Corporation, Walnut Creek, CA	280 + 428
Diquat + oxadiazon	Reward; Ronstar Flo	Syngenta Crop Protection, LLC; Greensboro, NC; Bayer Environmental Science, Research Triangle Park, NC	280 + 3,383
Flazasulfuron[b]	Katana	PBI Gordon Corporation, Kansas City, MO	52.5
Flumioxazin[b]	SureGuard	Valent USA Corporation, Walnut Creek, CA	428
Foramsulfuron[c]	Revolver	Bayer Environmental Science, Research Triangle Park, NC	28.9
Glufosinate	Finale	Bayer Environmental Science, Research Triangle Park, NC	840
Glufosinate	Finale	Bayer Environmental Science, Research Triangle Park, NC	1,680
Glufosinate + flumioxazin[b]	Finale; SureGaurd	Bayer Environmental Science, Research Triangle Park, NC; Valent USA Corporation, Walnut Creek, CA	840 + 428
Glufosinate + oxadiazon	Finale; Ronstar Flo	Bayer Environmental Science, Research Triangle Park, NC	840 + 3,383
Glyphosate	Roundup Pro Conc.	Monsanto Company, St. Louis, MO	390
Glyphosate	Roundup Pro Conc.	Monsanto Company, St. Louis, MO	520
Glyphosate + flumioxazin[b]	Roundup Pro Conc.; SureGaurd	Monsanto Company, St. Louis, MO; Valent USA Corporation, Walnut Creek, CA	390 + 428
Glyphosate + oxadiazon	Roundup Pro Conc.; Ronstar Flo	Monsanto Company, St. Louis, MO; Bayer Environmental Science, Research Triangle Park, NC	390 + 3,383
Metsulfuron + rimsulfuron[b]	Negate	Control Solutions Inc., Pasadena, TX	21.0 + 17.5
Oxadiazon	Ronstar Flo	Bayer Environmental Science, Research Triangle Park, NC	3,383
Trifloxysulfuron[b]	Monument 75WG	Syngenta Crop Protection, LLC, Greensboro, NC	18.3

[a]Experiments were conducted at Westlake Golf Course, Hardy, VA, and the Glade Road Research Facility, Blacksburg, VA, in 2016, 2017, 2018, and 2020.
[b]A nonionic surfactant was added at 0.25% v/v.
[c]Methylated seed oil at 1% v/v and ammonium sulfate (100% soluble granule) at 1,680 g ha^{-1} were added to the treatment.

Figure 2. Herbicides were applied to 'Zeon' zoysiagrass with less than 20 subcanopy green or partially green leaves dm^{-2} and 0% visible green cover at application timing to evaluate the effect of annual bluegrass control products on annual bluegrass and dormant Zeon zoysiagrass.

indicated that mecoprop + 2,4-D + dicamba controls hairy bittercress variably between 50% and 100% (Altland et al. 2000), but less information is available regarding hairy bittercress control in turfgrass settings. Hairy bittercress and common chickweed were evaluated for a shorter duration compared with that of the other weeds because of rapid senescence of plants in nontreated areas with summer heat.

The herbicide-by-year interaction for dandelion control at 56 DAT was likely caused by variable responses to glyphosate + simazine, indaziflam, and sulfentrazone (Table 3). However, other treatments responded similarly between years (Table 3). Glufosinate controlled dandelion by 96% to 99% and orders of magnitude better than glyphosate or diquat (Table 3). Glyphosate produced significantly better control of dandelion when it was mixed with simazine. Glufosinate, auxin-mimic products, florasulam-containing treatments, and metsulfuron-containing treatments were all equivalent to the best dandelion control observed in the study (Table 3). Variable and limited control of certain broadleaf weeds by glyphosate has been reported (Jordan et al. 1997; Koger et al. 2004, 2007; Shaw and Arnold 2002). Results from this study also coincide with other research findings that three- and four-way herbicide combinations, including auxin-type products,

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Table 3. Influence of broadleaf-herbicide treatments on common chickweed, hairy bittercress, dandelion, Persian speedwell, and annual bluegrass control.[a,b]

Treatment	Rate	Common chickweed[c]	Hairy bittercress[c]	Dandelion[d] 2017	Dandelion[d] 2018	Persian speedwell[d]	Annual bluegrass[d]
	g ai ha^{-1}	control %					
2,4-D + dicamba + fluroxypyr	1,680 + 210 + 210	73	78	95	97	31	1
MCPA + dicamba + triclopyr	1,470 + 147 + 147	68	80	94	96	28	1
2,4-D + dicamba + MCPP + carfentrazone	857 + 269 + 78.4 + 28	74	90	91	99	38	0
2,4-D + 2,4-DP + dicamba + carfentrazone	286 + 168 + 28 + 22.4	59	89	91	91	28	0
Diquat	560	94	95	10	14	44	30
Florasulam	14.7	82	68	94	96	14	1
Foramsulfuron	28.2	83	70	85	93	62	96
Foramsulfuron + florasulam	28.2 + 14.7	87	73	91	95	79	93
Foramsulfuron + halosulfuron + thiencarbazone	28.2 + 43.1 + 13.9	83	75	83	95	83	95
Glufosinate	1,680	99	99	96	99	92	77
Glyphosate	520	98	83	46	40	82	80
Glyphosate + simazine	520 + 2240	99	79	69	90	99	99
Indaziflam	32.6	56	77	53	15	64	17
Indaziflam + simazine	32.6 + 2240	99	86	58	43	99	97
Metsulfuron	21.0	91	84	86	99	59	14
Metsulfuron + sulfentrazone	42.0 + 420	96	85	89	99	78	21
Sulfentrazone	280	62	55	81	35	21	5
Least significant difference (0.05)		7	10	9	11	8	8

[a]Experiments were conducted at Virginia Tech Turfgrass Research Center, Blacksburg, VA, in March 2017 and 2018 with zoysiagrass. Green turf cover was 5% ± 3%, turf had 114 ± 30 green zoysiagrass leaves dm^{-2} distributed throughout the canopy, and growing degree days at base 5°C were 216 ± 46.
[b]Dandelion control was dependent on year, but all other weed responses are pooled over 2 site-years.
[c]Weed control at 28 d after treatment.
[d]Weed control at 56 d after treatment.

are effective options for controlling dandelion (Raudenbush and Keeley 2014).

Glufosinate, glyphosate + simazine, and indaziflam + simazine were the only herbicides that controlled Persian speedwell by more than 90% at 56 DAT (Table 3). Auxin-type herbicides did not control Persian speedwell by more than 38% (Table 3). Poor control of Persian speedwell and other speedwell species by auxin-type herbicides has been observed (Johnson 1976). The combination of metsulfuron + sulfentrazone controlled Persian speedwell 56 DAT more than either herbicide applied alone. This result with Persian speedwell contrasts with control of other broadleaf weeds in this study and that observed for two weeds in Tennessee and Texas where sulfentrazone admixture with metsulfuron enhanced initial weed phytotoxicity but did not improve long-term control over that of metsulfuron alone (Brosnan et al. 2012a).

Glyphosate and glufosinate controlled annual bluegrass by 77% to 80% and equivalently at 56 DAT (Table 3). Note, however, that glufosinate was applied at the maximum allowable rate for dormant turfgrass, while glyphosate was applied at 30% of the maximum allowable rate. Other researchers have reported similar annual bluegrass control between glyphosate and glufosinate in zoysiagrass turf (Toler et al. 2007; Xiong et al. 2013). Treatments that contained simazine or foramsulfuron controlled annual bluegrass by more than 90% and more than other treatments (Table 3). Previous research has indicated that foramsulfuron and simazine are effective annual bluegrass control options (Johnson 1982; Toler et al. 2007). However, over-reliance on simazine, glyphosate, and sulfonylurea herbicides such as foramsulfuron for annual bluegrass control has led to an increase in cases of annual bluegrass resistance to these herbicides (Breeden et al. 2017; Brosnan et al. 2020; Hutto et al. 2004).

The interaction of year by herbicide was significant for Meyer zoysiagrass green cover, NDVI, and injury AUPC d^{-1} ($P < 0.0001$); therefore, data are presented separately by year (Table 4). Variable weather conditions during the spring could have caused the interaction between year and treatments for green cover AUPC d^{-1}. The temperatures following treatment in 2018 were much warmer, leading to more rapid green turf cover, whereas 2020 temperatures were much cooler, resulting in slower post-dormancy transition. Specific treatments that may have caused the interaction include any combination containing glufosinate, glyphosate, or metsulfuron (Table 4). Increased herbicidal injury during the warmer 2018 conditions likely reduced green cover in 2018 compared with 2020 for treatments containing these herbicides. Other treatments were reasonably consistent between year with respect to green cover AUPC per day. Nontreated zoysiagrass maintained an average green cover per dayd^{-1} of 70% to 82% (Table 4). Note that treatments were initiated at approximately 5% green turf cover and reached near 100% cover in nontreated plots by 56 DAT (data not shown). Thus, the AUPC per day in nontreated plots does not reflect green cover of actively growing turf because the turf was initially breaking dormancy during the first half of the evaluation period. Dinalli et al. (2015) noted that metsulfuron caused severe phytotoxicity to 'Emerald' zoysiagrass. Dernoeden (1994) concluded that metsulfuron was too injurious to Meyer zoysiagrass. Glufosinate reduced zoysiagrass green cover per day more than all other treatments (Table 4). Similarly, cover reduction or "delayed green-up" has been reported when both glyphosate and glufosinate were applied to semi-dormant zoysiagrass turf (Xiong et al. 2013).

The interaction of year by treatment for NDVI AUPC per day was caused by several treatments having lower NDVI per day from the colder conditions of 2020 compared with 2018 (Table 4). NDVI trends could be explained by dead or dying weeds, variable temperatures, and frost-associated zoysiagrass injury, or other unknown factors between years. The NDVI per day data supported observations of reduced cover per day by glufosinate with lower NDVI values compared to all other treatments in both years, just as it did regarding green cover (Table 4).

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Table 4. Influence of broadleaf-herbicide treatments on average daily 'Meyer' zoysiagrass green cover, normalized difference vegetation index, and visually estimated injury based on area under the progress curve following seven assessments over a 70-d period after treatment.[a,b]

Treatment	Rate	Green cover		NDVI		Injury	
		2018	2020	2018	2020	2018	2020
	g ai ha^{-1}	AUPC d^{-1}					
Nontreated		70	82	0.687	0.629	–	–
2,4-D + dicamba + fluroxypyr	1,680 + 210 + 210	69	81	0.679	0.612	0	0
MCPA + dicamba + triclopyr	1,470 + 147 + 147	70	77	0.600	0.554	1	4
2,4-D + dicamba + MCPP + carfentrazone	857 + 269 + 78.4 + 28	70	78	0.685	0.557	0	3
2,4-D + 2,4-DP + dicamba + carfentrazone	286 + 168 + 28 + 22.4	67	82	0.670	0.635	0	0
Diquat	560	63	72	0.600	0.562	39	19
Florasulam	14.7	70	80	0.688	0.593	0	0
Foramsulfuron	28.2	66	78	0.673	0.591	9	0
Foramsulfuron + florasulam	28.2 + 14.7	64	79	0.663	0.592	11	6
Foramsulfuron + halosulfuron + thiencarbazone	28.2 + 43.1 + 13.9	64	76	0.678	0.591	9	2
Glufosinate	1,680	19	45	0.386	0.507	83	57
Glyphosate	520	50	78	0.610	0.589	32	2
Glyphosate + simazine	520 + 2240	44	77	0.573	0.574	35	4
Indaziflam	32.6	69	79	0.682	0.604	1	0
Indaziflam + simazine	32.6 + 2240	72	78	0.704	0.582	0	0
Metsulfuron	21.0	53	72	0.609	0.591	25	21
Metsulfuron + sulfentrazone	42.0 + 420	46	71	0.595	0.550	32	21
Sulfentrazone	280	67	80	0.685	0.599	2	0
LSD (0.05)		3	4	0.028	0.043	4	4

[a]Experiments were carried out at the Virginia Tech Turfgrass Research Center, Blacksburg, VA, in March 2018 and 2020, with 5% ± 3% green turf cover of 'Meyer' zoysiagrass. Turf had 82 ± 11 green zoysiagrass leaves dm^{-2} distributed throughout the canopy, and growing degree days at base 5 C were 162 ± 6.
[b]Abbreviations: AUPC, area under the progress curve; NDVI, normalized difference vegetation index.

Upon examining injury AUPC per day, it is evident that higher injury levels in the warmer 2018 spring season compared with the cooler 2020 spring season caused the year-by-treatment interaction for turfgrass injury, cover, and NDVI. In 2018, diquat, glufosinate, glyphosate, glyphosate + simazine, and metsulfuron + sulfentrazone were the only treatments that produced an injury AUPC per day above a commercially acceptable injury threshold of 30% (Table 4). Glufosinate caused an injury AUPC per day of 83% and 57% to zoysiagrass in 2018 and 2020, respectively (Table 4). However, glufosinate was the only treatment that caused an injury AUPC per day above 30% to turfgrass in 2020 (Table 4). In order to average 30% injury per day during the entire evaluation period, these herbicides had to be highly injurious to the turf or cause moderate levels of injury that persisted for most of the 70-d evaluation period. Thus, any treatment with an injury of >20 AUPC d^{-1} is likely too injurious to use on semidormant zoysiagrass turf. In other studies, glyphosate and glufosinate injured zoysiagrass if it was applied when small percentages of green cover were apparent at treatment time (Rimi et al. 2012; Xiong et al. 2013). However, previous research has not observed glufosinate being more injurious than glyphosate (Xiong et al. 2013). The weather conditions following initiation of the 2020 studies were not as warm and did not favor zoysiagrass shoot development or herbicidal activity. Late frosts appeared to halt slow post-dormancy transition, possibly masking herbicide injury or partially safening the turfgrass due to reduced herbicidal activity. Weather conditions following 2018 treatments favored rapid shoot development and herbicidal activity, allowing maximum contrast between rapidly growing green turf and stunted or discolored turf.

Effect of Annual Bluegrass Control Products on Annual Bluegrass and dormant Zeon Zoysiagrass

The year-by-herbicide interaction was not significant for annual bluegrass cover AUPC per day ($P = 0.1065$), cover at 84 DAT ($P = 0.1168$), annual bluegrass control AUPC per day ($P = 0.0601$), and annual bluegrass control at 84 DAT ($P = 0.0874$). The herbicide main effect was significant for the above-mentioned response variables ($P < 0.0001$); therefore, data were pooled over the years (Table 5). Annual bluegrass control by both glyphosate and glufosinate was rate dependent. Glufosinate and diquat controlled annual bluegrass less than glyphosate based on both AUPC per day and observed values at 84 DAT except glyphosate versus glufosinate, each at higher rates for AUPC per day only (Table 5). The comparison of glyphosate and glufosinate at high rates being similar to control bluegrass per day but different at 84 DAT suggest that initial annual bluegrass control was equivalent for the two, as was found by other researchers (Toler et al. 2007; Xiong et al. 2013), but annual bluegrass recovered more over time following glufosinate treatment. The addition of flumioxazin to diquat, glufosinate, or glyphosate improved annual bluegrass control per day and final control at 84 DAT, but such improvement did not occur with oxadiazon admixture (Table 5). Reed et al. (2015) also observed that flumioxazin tank-mixed with glyphosate was more effective than flumioxazin alone. Our results contrast with reports that combining contact-type modes of action herbicides with glyphosate could decrease weed control (Wehtje et al. 2008, 2010).

Foramsulfuron controlled 92% of annual bluegrass at 84 DAT, equivalent to annual bluegrass control achieved by applying glyphosate (520 g ae ha^{-1}) and glyphosate (390 g ae ha^{-1}) + flumioxazin; but greater than all other treatments evaluated (Table 5). Among sulfonylurea herbicides, annual bluegrass control was greatest to least in the following order: foramsulfuron > trifloxysulfuron > metsulfuron + rimsulfuron > flazasulfuron (Table 5). Foramsulfuron and trifloxysulfuron have been superior-performing sulfonylurea treatments in previous research (Harrell et al. 2005; Toler et al. 2007). Flazasulfuron has controlled annual bluegrass inconsistently in past research. Harrell et al. (2005) reported 49% and 92% annual bluegrass control in 2002 and 2003, respectively. Toler et al. (2007) reported that flazasulfuron controlled

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Table 5. Effect of annual-bluegrass-herbicide treatments on final and average-daily annual bluegrass cover and control when applied to dormant 'Zeon' zoysiagrass.[a,b,c,d]

Treatment	Rate	Annual bluegrass control		Annual bluegrass cover	
	g ai ha^{-1}	AUPC d^{-1}	84 DAT	AUPC d^{-1}	84 DAT
Nontreated	–	–	–	59	50
Diquat	280	13	6	52	49
Diquat	560	17	5	51	46
Diquat + flumioxazin	280 + 428	41	45	36	24
Diquat + oxadiazon	280 + 3,383	28	18	43	38
Flazasulfuron	52.5	46	51	33	27
Flumioxazin	428	45	54	25	14
Foramsulfuron	28.9	65	92	18	4
Glufosinate	840	53	38	28	32
Glufosinate	1,680	77	65	14	19
Glufosinate + flumioxazin	840 + 428	76	75	13	11
Glufosinate + oxadiazon	840 + 3,383	56	40	26	31
Glyphosate	390	72	75	13	14
Glyphosate	520	80	88	10	7
Glyphosate + flumioxazin	390 + 428	78	88	14	9
Glyphosate + oxadiazon	390 + 3,383	74	71	12	14
Metsulfuron + rimsulfuron	21.0 + 17.5	53	62	28	23
Oxadiazon	3,383	5	3	55	47
Trifloxysulfuron	18.3	62	80	23	16
LSD (0.05)	–	4	8	9	10

[a]Abbreviations: AUPC, area under the progress curve; DAT, days after treatment.
[b]A total of 3 site-year experiments were conducted on 1.3-cm 'Zeon' zoysiagrass fairways with natural infestations of annual bluegrass comprising 30% to 50% coverage of 10- to 20-tiller annual bluegrass plants at Westlake Golf Course, Hardy, VA, in 2016, 2017, and 2018. In 2020, a study was conducted on a separate 1.3-cm research fairway of Zeon zoysiagrass with a natural infestation of annual bluegrass comprising 3% to 5% coverage of 5- to 10-tiller plants at the Glade Road Research Facility at Virginia Tech University in Blacksburg, VA.
[c]Average daily values are based on the area under the progress curve following nine assessments over an 84-d period after treatment in late February to early March in 2016, 2017, 2018, and 2020 when zoysiagrass had no green turf cover and less than 20 subcanopy green or partially green leaves dm^{-2} and growing degree days at base 5 C were 97± 67.
[d]All responses are pooled over 4 site-years.

annual bluegrass by 97%. The performance of flazasulfuron may have been reduced due to the maturity of annual bluegrass when the herbicide was applied.

Annual bluegrass cover AUPC per day in nontreated plots was slightly greater than final cover observations at 84 DAT (Table 5). This occurred because the initially observed cover was near maxima, which was reached between 28 and 42 DAT, and then declined slightly as temperatures warmed as summer began (data not shown). These cover data reflect that annual bluegrass infestation was severe, but they are indicative of winter weed issues on dormant turf. Annual bluegrass infestations were so extensive that we expanded our experimental plot sizes to 3.6 m long at Westlake to improve the assessment of zoysiagrass response to herbicides. The best-performing treatments based on annual bluegrass control included glyphosate at 520 g ae ha^{-1}, glyphosate at 390 g ae ha^{-1} + flumioxazin, and foramsulfuron, which still had 4.0% to 8.6% annual bluegrass cover at 84 DAT (Table 5). Regardless of the rate, the annual bluegrass cover AUPC per day was significantly less with glyphosate and glufosinate than with diquat (Table 5). Only diquat at both rates and oxadiazon alone did not alter annual bluegrass cover AUPC per day or final cover at 84 DAT compared with the nontreated plots (Table 5). These data suggest that diquat applied in the spring does not reduce annual bluegrass cover, and this is supported by previous research (Toler et al. 2007). Overall, annual bluegrass cover and AUPC per day data were negatively related to annual bluegrass control.

The interaction between year and herbicide was not significant for injury maxima ($P = 0.0641$) and green cover ($P = 0.3810$; Table 6). The herbicide main effect was significant for injury maxima ($P = 0.0003$) and green cover ($P = 0.0263$); therefore, data were pooled over years. The interaction between year and herbicide was significant for injury ($P < 0.0001$) and NDVI ($P = 0.0039$) AUPC per day; therefore, data are presented separately (Table 6). Metsulfuron + rimsulfuron injured dormant Zeon zoysiagrass by 39% and was the only treatment that exceeded the acceptable injury threshold of 30% (Table 6). These data suggest that all other treatments could be safely applied to "fully dormant" zoysiagrass and they agree with other reports of minimal injury response from glyphosate and glufosinate when applied during dormancy (Rimi et al. 2012; Xiong et al. 2013). However, near-threshold injury occurred following glufosinate applied at 1,680 g ai ha^{-1}, flumioxazin, flumioxazin + glyphosate, and flumioxazin + glufosinate (Table 6). These near-threshold levels of injury are a cause of concern because data in Table 4 and from other reports (Rimi et al. 2012; Velsor et al. 1989; Xiong et al. 2013) indicate that herbicide injury may substantially increase as zoysiagrass green cover begins to increase in the season. Thus, these herbicides may be safely applied during dormancy but must be scrutinized if any zoysiagrass green cover is detected at the canopy surface. Injury maxima of glufosinate at both rates was significantly higher than glyphosate at both rates (Table 6). Metsulfuron + rimsulfuron would not be recommended for use in dormant zoysiagrass (Table 6).

The interaction between year and herbicide treatment for injury AUPC per day can be primarily attributed to variable zoysiagrass response to metsulfuron + rimsulfuron among years (Table 6). In 2016, spikes in initial injury were followed by rapid recovery compared to more persistent injury levels in 2017 and 2020 and a substantial change of several orders of magnitude in injury AUPC per day data between those years (Table 6). Glufosinate at the higher rate caused significantly more injury per day to dormant zoysiagrass than glyphosate applied at a higher rate in 2016 and 2020 (Table 6). Injury per day generally agrees with injury maxima data; however, variable recovery speed following initial injury may explain slight changes in injury per day between years.

Table 6. Influence of annual bluegrass herbicide treatments on dormant Zeon zoysiagrass.[a,b,c,d]

Treatment	Rate	Injury maxima	Injury			NDVI		Green cover
			2016	2017	2020	2017	2020	
	g ha^{-1}	%	AUPC d^{-1}					
Nontreated	–	–	–	–	–	0.426	0.611	44
Diquat	280	1	0	1	0	0.412	0.618	44
Diquat	560	4	1	1	0	0.425	0.580	42
Diquat + flumioxazin	280 + 428	10	2	6	3	0.392	0.543	41
Diquat + oxadiazon	280 + 3,383	7	4	1	0	0.416	0.574	39
Flazasulfuron	52.5	10	3	3	1	0.419	0.621	43
Flumioxazin	428	22	10	5	9	0.408	0.557	39
Foramsulfuron	28.9	4	2	1	0	0.418	0.599	44
Glufosinate	840	13	7	3	0	0.421	0.617	41
Glufosinate	1,680	25	7	8	8	0.392	0.501	41
Glufosinate + flumioxazin	840 + 428	22	7	7	11	0.376	0.539	38
Glufosinate + oxadiazon	840 + 3,383	9	0	5	3	0.397	0.590	42
Glyphosate	390	4	1	1	0	0.398	0.612	44
Glyphosate	520	8	2	5	0	0.388	0.589	45
Glyphosate + flumioxazin	390 + 428	25	11	8	9	0.399	0.554	42
Glyphosate + oxadiazon	390 + 3,383	8	2	3	2	0.384	0.608	43
Oxadiazon	3383	3	2	0	0	0.437	0.605	42
Metsulfuron + rimsulfuron	21.0 + 17.5	39	4	11	28	0.427	0.551	37
Trifloxysulfuron	18.3	9	5	3	0	0.438	0.592	42
LSD (0.05)		7	4	4	5	0.037	0.036	4

[a]Abbreviations: AUPC, area under the progress curve; NDVI, normalized difference vegetation index.
[b]Herbicides were applied in late February to early March 2016, 2017, and 2020 when zoysiagrass had no green turf cover, less than 20 subcanopy green or partially green leaves dm^{-2}, and growing degree days at base 5 C were 97 ± 67.
[c]Percentage injury maxima and green cover AUPC d^{-1} are pooled over 3 site-years.
[d]Injury and NDVI were separated by 3 yr and 2 yr, respectively, due to significant year-by-treatment interaction. Zoysiagrass response data from an additional trial in 2018 was confounded by winter kill and disease and was omitted.

Interactions of year by herbicide treatment for NDVI AUPC per day could be attributed to varying levels of green cover, weed density, and herbicidal activity among years (Table 6). The 2017 data were collected at Westlake, where annual bluegrass populations comprised more than half of the turf, whereas the 2020 data were collected at the GRRF, where annual bluegrass populations constituted only 5% of the turf canopy. Glyphosate used at 390 g ae ha^{-1} resulted in lower NDVI per day in 2017 compared to other treatments but comparable to the best NDVI per day in 2020 (Table 6). This rate of glyphosate did not injure zoysiagrass, but it did control annual bluegrass. The different NDVI responses between site-years were primarily driven by herbicidal effects on the large annual bluegrass populations at Westlake in 2017. In 2020, NDVI per day better supports variation in herbicidal injury since the more injurious herbicide treatments (glufosinate at 1,680 g ai ha^{-1} and metsulfuron + rimsulfuron) resulted in the lowest NDVI per day (Table 6). Zoysiagrass green cover AUPC per day tended to ignore transient peak-injury responses and better indicate the treatments that cause unacceptable effects on turf development. In general, most treatments minimally impacted post-dormancy transition and associated green cover when applied to dormant zoysiagrass (Table 6). Only three treatments, including flumioxazin, flumioxazin + glufosinate, and metsulfuron + rimsulfuron, had green turf cover per day lower than the nontreated plots (Table 6). The above-mentioned three treatments were among the most injurious to dormant zoysiagrass.

Results of these studies suggest that a wide range of herbicides could be used to control weeds in semidormant Meyer and dormant Zeon zoysiagrass. However, metsulfuron + rimsulfuron is too injurious to zoysiagrass when applied just before spring green-up. High rates of glufosinate and flumioxazin do not injure dormant zoysiagrass to an unacceptable degree but their injury potential warrants concern. Diquat, glufosinate, glyphosate, and metsulfuron caused commercially unacceptable levels of injury to the Meyer zoysiagrass with 5% green turf cover at the rates assessed in these studies. Glufosinate was more injurious to zoysiagrass than glyphosate or diquat, regardless of dormancy level. Our research finding contrasts with the only paper that compared glufosinate and glyphosate in similar situations and found them equivalent for zoysiagrass response (Xiong et al. 2013). Broadleaf weed control by the herbicide treatments tested is weed-species dependent, but a wide range of products can be safely used in zoysiagrass for that purpose. Annual bluegrass control, assuming herbicide-resistant biotypes are not present, is acceptable with foramsulfuron, glyphosate, high glufosinate rates, and simazine.

Practical Implications

Applying nonselective herbicides for annual bluegrass control at 97 GDD_{5C} appears to impart additional safety to Zeon zoysiagrass compared with herbicides applied later in spring (Craft et al. 2023). Information on sensitivity of *Zoysia matrella* during post-dormancy transition is lacking in the scientific literature and this work does little to fill this information gap because our studies on Zeon zoysiagrass were conducted during winter dormancy to target annual bluegrass. Other research has shown that Meyer zoysiagrass response to nonselective herbicides is dependent on the product and application timing (Craft et al. 2023). These research findings documented several viable herbicide options that can be used to control broadleaf weeds in Meyer zoysiagrass during post-dormancy transition without compromising turfgrass safety. Acceptable annual bluegrass control can be achieved with foramsulfuron, glyphosate, high rates of glufosinate, and simazine; however, the turfgrass sites we evaluated had no history of herbicide-resistant annual bluegrass biotypes. Practitioners should choose weed control programs depending on herbicide-resistant weed scenarios and be mindful of growing degree day accumulation and turfgrass green cover at the time of treatment.

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