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Seashore Paspalum (*Paspalum vaginatum*) Tolerance to Pronamide Applications for Annual Bluegrass Control

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Annual bluegrass is a troublesome weed in turf management and there are currently limited POST herbicides labeled for use in seashore paspalum. Field and greenhouse experiments were conducted to evaluate seashore paspalum tolerance to pronamide and other herbicides for annual bluegrass control. In field experiments, turf injury never exceeded 7% from pronamide applied at dormancy, 50% green-up, or complete green-up of seashore paspalum in spring. Annual bluegrass control from pronamide was initially similar across timings and averaged 67, 90, and 98% control from 0.84, 1.68, and 3.36 kg ai ha^{-1}, respectively, after 6 wk. In greenhouse experiments, the aforementioned pronamide rates caused less than 10% injury on seashore paspalum. Seashore paspalum injury in the greenhouse was excessive ($>$ 20%) from atrazine, bispyribac-sodium, and trifloxysulfuron and moderate (7 to 20%) from foramsulfuron, rimsulfuron, and ethofumesate. Seashore paspalum seedhead count reductions by 4 wk after treatment (WAT) were good to excellent (87 to 98%) from atrazine, bispyribac-sodium, rimsulfuron, and trifloxysulfuron and poor ($\leq$ 0%) from ethofumesate, foramsulfuron, and pronamide. By 4 WAT, seashore paspalum clippings were reduced 0 to 39% from pronamide, whereas atrazine, bispyribac-sodium, and trifloxysulfuron reduced clippings by 54 to 69% from the untreated and ethofumesate, foramsulfuron, and rimsulfuron reduced clippings by 27 to 39%.
Nomenclature: Annual bluegrass, *Poa annua* L.; seashore paspalum, *Paspalum vaginatum* Sw.
Key words: Pronamide, turfgrass, weed control.

Poa annua es una maleza problemática en el manejo de césped y actualmente no existe un herbicida posemergente eficaz recomendado para su uso en *Paspalum vaginatum*. Se condujeron experimentos de campo y de invernadero para evaluar la tolerancia de *P. vaginatum* a pronamide y otros herbicidas en el control de *P. annua.* En los experimentos de campo, el daño al césped nunca fue más de 7% con pronamide aplicado en dormancia, en 50% de reverdecimiento o en reverdecimiento total de *P. vaginatum* en la primavera. El control de *P. annua* con pronamide fue inicialmente similar en los tres momentos de aplicación y promedió 67, 90 y 98% de control a partir de 0.84, 1.68 y 3.36 kg i.a. ha^{-1}, respectivamente, después de 6 semanas. En los experimentos de invernadero, las dosis anteriormente mencionadas de pronamide causaron menos de 10% de daño en *P. vaginatum.* El daño de *P. vaginatum* en el invernadero fue excesivo ($>$20%) cuando se aplicaron atrazina, bispyribac-sodium, y trifloxysulfuron, y fue moderado (de 10 a 20%) cuando se aplicó foramsulfuron, rimsulfuron y ethofumesate. Las reducciones en el número de cabezuelas de *P. vaginatum* a las 4 semanas después de la aplicación, fueron de buenas a excelentes (de 87 a 98%) con atrazina, bispyribac-sodium, rimsulfuron y trifloxysulfuron fueron pobres ($<$70%) con ethofumesate, foramsulfuron y pronamide. A las 4 semanas después de la aplicación, los recortes de *P. vaginatum* se redujeron de 0 a 39% con pronamide, mientras que atrazina, bispyribac-sodium y trifloxysulfuron redujeron los recortes de 54 a 69% en comparación con el testigo no tratado, y ethofumesate, foramsulfuron y rimsulfuron redujeron los recortes en 27 a 39%.

Seashore paspalum is a warm-season turfgrass used for golf greens, tees, fairways, and roughs in coastal, tropical, and warm temperate regions (Dudeck and Peackock 1985; Morton 1973; Skerman and Riveros 1990). Seashore paspalum is well adapted to adverse environmental conditions because of high tolerances to salt, drought, water logging, and low soil pH (Coleman and Wilson 1960; Duncan 1994; Jiang et al. 2004; Skerman and Riveros 1990). Recently introduced seashore paspalum cultivars, such as ‘Sea Isle Supreme’ and ‘Sea Isle 1’, exhibit dark green color, fine leaf texture, and tolerate close mowing, traffic, high-salt soils, and irrigation with salt-laden water (Duncan 1999; Jiang et al. 2004; Trenholm et al. 1999, 2000). Despite these desirable qualities for management, practitioners have have limited POST herbicides available for controlling problematic weeds in seashore paspalum.

Annual bluegrass is a winter annual weed that reduces aesthetics, functionality, and surface quality of turfgrasses (Beard 1970). Annual bluegrass is undesirable in fine turf because of a lighter green color, shallow root system, and unsightly seedhead production (Lush 1989; Sprague and Burton 1937). Annual bluegrass tolerates close mowing and germinates rapidly, but has poor disease, drought, and wear tolerances that create unsightly patches in turfgrass stands (Beard et al. 1978; Kaminski and Dernoeden 2007; Lush 1989;). Consequently, turf infested with annual bluegrass requires more intensive management to maintain acceptable quality and control with herbicides is often warranted.

PRE herbicides including dinitroanilines and oxadiazon may be applied in fall for annual bluegrass control in seashore paspalum (Bhowmik and Bingham 1990; Goss 1964; Johnson 1977). POST annual bluegrass control is difficult because of a lack of selective herbicides safe for use in seashore paspalum.

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Sulfonylureas such as foramsulfuron, rimsulfuron, and trifloxysulfuron are effective POST herbicides for annual bluegrass control in warm-season grasses but may cause excessive injury (> 20%) to seashore paspalum (Johnson and Duncan 2000; Patton et al. 2009; Toler et al. 2007; Unruh et al. 2006). Ethofumesate has potential for use in seashore paspalum but applications are limited to early POST timings for annual bluegrass control as efficacy is often reduced on mature plants in spring (Coats and Krans 1986; Johnson 1983). Furthermore, seashore paspalum has shown excessive injury to ethofumesate applications at rates required for annual bluegrass control and practitioners need POST chemistries with less potential for turfgrass phytotoxicity (Johnson and Duncan 2000; Unruh et al. 2006).

Pronamide is an amide herbicide with PRE and POST activity for annual bluegrass control (Senseman 2007). Pronamide is currently labeled for use in most major warm-season turfgrasses but research is limited for use in seashore paspalum (Anonymous 2009). In field experiments, pronamide has shown potential to selectively control annual bluegrass without injuring seashore paspalum (personal observation) but rates and application timings during spring green-up have received limited investigation. The objective of this research was to (1) investigate seashore paspalum tolerance to pronamide for POST annual bluegrass control at various spring application timings and (2) investigate seashore paspalum growth responses to pronamide and other POST herbicides used for annual bluegrass control in turf.

Materials and Methods

Field Experiments. Experiments were conducted in Griffin, GA from February to May 2009 and 2011 on a mature stand of Sea Isle 1 seashore paspalum. Plots used in the 2011 experiment were adjacent to plots in 2009. Turf was grown on a Cecil sandy loam (fine, kaolinitic, thermic Typic Kanhapludults) with approximately 2% organic matter and a 6.0 pH. In 2009, seashore paspalum averaged 36% (±2.1) annual bluegrass cover on March 11. In September 2010, seashore paspalum was treated with a PRE herbicide for winter annual weed control. Therefore, treatments were applied on two fields in 2011 including the aforementioned seashore paspalum and a 'TifSport' bermudagrass with 26% (±1.3) annual bluegrass cover on February 21. Annual bluegrass in both years was an annual biotype and approximately 50% of the populations had seedheads present on the day of initial treatments. Seashore paspalum and bermudagrass were irrigated to prevent wilt and mowed 3 d per week during active growth with a reel mower at 1.3-cm height with clippings returned.

The experimental design was a randomized complete block with four replications of 0.9- by 3-m plots. Treatments were the factorial combination of three pronamide (Kerb 50W [pronamide], Dow Agrosciences LLC, 9330 Zionsville Road, Indianapolis, IN 46268) rates, 0.84, 1.68, or 3.36 kg ai ha^{-1}, applied at three growth stages of seashore paspalum including complete dormancy, transitional spring growth (50% green-up), or active growth (100% green-up). Treatments were applied on March 11, April 1, and April 15 in 2009 and February 21, March 11, and April 1 in 2011 for dormancy, 50% green-up, and 100% green-up, respectively. Treatments were applied using CO_2-pressured sprayers calibrated to deliver 374 L ha^{-1} with a single flat-fan nozzle (Tee Jet Spraying Systems Co., Roswell, GA 30075) and plots received approximately 1 cm of irrigation immediately after applications.

Annual bluegrass ground cover was visually rated on a percent scale where 0 equaled no cover and 100 equaled complete cover. Control was calculated as percent reductions from the untreated in each replication using the following equation:

$$\text{Control} = 100 \times ([\text{cover}_0 - \text{cover}_x]/\text{cover}_0) \qquad [1]$$

where cover_0 and cover_x were percent annual bluegrass cover of the untreated and treated, respectively. Data were subjected to ANOVA at the 0.05 probability level with SAS (SAS Institute, Cary, NC). Means were separated using Fisher's Protected LSD test at $P = 0.05$. Year-by-treatment interactions were not detected for seashore paspalum injury, and thus years were combined.

Greenhouse Experiments. Two separate experiments were conducted in a greenhouse at the University of Georgia in Griffin, GA from June to August 2011. Greenhouse day/night temperatures were set for 30/24 C with approximately 12 h of light. Sea Isle 1 seashore paspalum sod was collected from a mature fairway in Griffin, GA grown on a sandy loam with approximately 2% organic matter and pH of 6.0. Sod was placed in pots with 1-dm^2 surface areas and 10-cm depths filled with similar-to-the-aforementioned soil. Seashore paspalum was clipped weekly with shears at a 2.5-cm mowing height and allowed to resume active growth before herbicide applications.

Experimental design was a randomized complete block with four replications. Blocks were rotated and pots were randomized weekly to minimize greenhouse variability. Treatments included pronamide at 0, 0.84, 1.68, or 3.36 kg ai ha^{-1}, atrazine (Aatrex 4L [atrazine], Syngenta Crop Protection, Inc., P.O. Box 18300, Greensboro, NC 27419-8300) at 2.24 kg ai ha^{-1}, bispyribac-sodium (Velocity 80WP [bispyribac-sodium], Valent U.S.A. Corp., P.O. Box 8025, Walnut Creek, CA 94596) at 0.11 kg ai ha^{-1}, ethofumesate (Prograss 1.5EC [ethofumesate], Bayer Environmental Sciences, 95 Chestnut Ridge Road, Montvale, NJ 07645) at 1.68 kg ai ha^{-1}, foramsulfuron (Revolver 0.19SC [foramsulfuron], Bayer Environmental Sciences, Research Triangle Park, NC 27709) at 0.03 kg ai ha^{-1}, rimsulfuron (TranXit GTA 25DF [rimsulfuron], E. I. DuPont de Nemours and Company, Wilmington, DE 19898) at 0.04 kg ai ha^{-1}, and trifloxysulfuron (Monument 75WG [trifloxysulfuron-sodium], Syngenta Crop Protection, Inc., P.O. Box 18300. Greensboro, NC 27419-8300) at 0.03 kg ai ha^{-1}. These rates were chosen on the basis of label recommendations for annual bluegrass control. A nonionic surfactant (Chem Nut 80-20, a mixture of alkyl and alkylaryl polyoxyethylene glycol, 80%, Chem Nut Inc., P.O. Box 3706, Albany, GA 31706) was included with foramsulfuron, rimsulfuron, and trifloxysulfuron treatments. Pronamide-treated pots received approximately 1 cm of irrigation after applications.

Table 1. ‘Sea Isle 1’ seashore paspalum injury from pronamide in field experiments, 2009 and 2011, Griffin, GA.

Application timing[a]	Pronamide[b]	Seashore paspalum injury (WAT)[ac] 3	6	9
	kg ai ha^{-1}	%		
Dormancy	0.84	3	0	0
	1.68	4	1	0
	3.36	5	7	0
50% Green-up	0.84	1	0	0
	1.68	0	0	0
	3.36	6	0	0
100% Green-up	0.84	1	0	0
	1.68	1	0	0
	3.36	3	0	0
$LSD_{0.05}$		NS	2	NS

[a] Applications were made at three timings relative to seashore paspalum growth stage from 100% dormancy to 100% green-up. Applications were made on March 11, April 1, and April 15, 2009 and February 21, March 11, and April 1 in 2011 for dormancy, 50% green-up, and 100% green-up, respectively. In 2009, treatments were applied to Sea Isle 1 seashore paspalum for annual bluegrass control evaluations. In 2011, treatments were applied on the same dates to Sea Isle 1 seashore paspalum for turf tolerance and ‘TifSport’ bermduagrass for annual bluegrass control evaluations. Both fields were maintained as fairways with a 1.3-cm mowing height.

[b] Pronamide product used was Kerb® 50WP, Dow Agrosciences, Indianapolis, IN.

[c] Abbreviations: WAT, weeks after treatment; NS, not significant at the 0.05 probability level.

Seashore paspalum injury was rated 2 and 4 wk after treatment (WAT) on a percent scale where 0 equaled no injury from the untreated and 100 equaled completely dead grass. Seedheads were counted 4 WAT in every pot. Clippings were harvested 4 WAT, oven dried at 60 C, and then weighed. Data were subjected to ANOVA and significance of main effects were analyzed at the 0.05 probability level. Means were separated with Fisher’s Protected LSD test at á = 0.05. Experiment-by-treatment interactions were not detected for measurements and thus experiments were combined.

Results and Discussion

Field Experiments. Pronamide rate-by-application timing interactions were detected for seashore paspalum injury at one evaluation date. Turf injury was similar across pronamide rates and application timings by 3 WAT and did not exceed 6% (Table 1). By 6 WAT, seashore paspalum was injured 7% from pronamide at 3.36 kg ha^{-1} when applied at dormancy but all other pronamide treatments injured turf less than 2%. Injury was not detected by 9 WAT from any pronamide treatment, which is similar to previous reports on bermudagrass (Johnson 1976).

Seashore paspalum tolerance to pronamide in spring appears comparable with bermudagrass (*Cynodon dactylon* (L.) Pers.), centipedegrass (*Eremochloa ophiuroides* (Munro) Harck.), and zoysiagrass (*Zoysia* spp.) (Johnson 1974, 1990; Patton 2007). These turf species, with the exception of seashore paspalum, are currently labeled for pronamide use, suggesting amendments are needed to include seashore paspalum on product labels (Anonymous 2009). Although mature seashore paspalum appears tolerant in spring, practitioners should be cautious when using pronamide on newly established seashore paspalum. In Arkansas, researchers noted that pronamide caused approximately 20% injury to ‘Sea Spray’ seashore paspalum seedlings 8 d after treatment, suggesting that pronamide applications should be limited to mature stands only (Patton et al. 2009).

Table 2. Annual bluegrass control following treatments of pronamide at three application timings relative to ‘Sea Isle 1’ seashore paspalum growth in field experiments, 2009 and 2011, Griffin, GA.

Application timing[a]	Annual bluegrass control: 3 WAT[b] (2009 + 2011)	6 WAT (2009)[c]	6 WAT (2011)
	%		
Dormancy	55	80	95
50% Green-up	52	87	88
100% Green-up	56		85
$LSD_{0.05}$	NS	NS	6
Pronamide[d] (kg ai ha^{-1})			
0.84	49	62	72
1.68	54	92	97
3.36	60	97	98
$LSD_{0.05}$	NS	22	6

[a] Applications were made at three timings relative to seashore paspalum growth stage from 100% dormancy to 100% green-up. Applications were made on March 11, April 1, and April 15, 2009 and February 21, March 11, and April 1 in 2011 for dormancy, 50% green-up, and 100% green-up, respectively. In 2009, treatments were applied to Sea Isle 1 seashore paspalum for annual bluegrass control evaluations. In 2011, treatments were applied on the same dates to Sea Isle 1 seashore paspalum for turf tolerance and ‘TifSport’ bermduagrass for annual bluegrass control evaluations. Both fields were maintained as fairways at the University of Georgia Griffin campus with a 1.3-cm mowing height.

[b] Abbreviations: WAT, weeks after treatments; NS, not significant at the 0.05 probability level.

[c] By 6 WAT in 2009 annual bluegrass populations had completely died out in plots. Data presented on this date for 100% green-up application timing represents 2011 only.

[d] Pronamide product used was Kerb® 50WP, Dow Agrosciences, Indianapolis, IN.

Seashore paspalum appeared to have acceptable tolerance levels to pronamide rates that also effectively controlled annual bluegrass. Pronamide rate-by-application timing interactions were not detected for annual bluegrass control. By 3 WAT in both years, annual bluegrass control was similar across pronamide rates, ranging 49 to 60% (Table 2). By 6 WAT in both years, pronamide at 1.68 and 3.36 kg ha^{-1} provided excellent (≥ 90%) annual bluegrass control but 0.84 kg ha^{-1} was unacceptable (< 75% control).

The influence of application timing was not significant by 3 WAT for annual bluegrass control in both years (Table 2). In 2009, annual bluegrass control from pronamide applied at dormancy was similar to treatments applied at 50% green-up by 6 WAT. In 2011, dormant applications were most effective, averaging 95% control by 6 WAT, whereas the later timings averaged 85 to 88% control across pronamide rates. Annual bluegrass had completely died out in the untreated plots by 6 wk after the late application timing in 2009, and control was not evaluated on this date. Results are similar to previous research with pronamide for controlling cool-season grassy weeds as desired efficacy is typically observed by 4 to 6 wk after application (Johnson 1976, 1990).

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Table 3. 'Sea Isle 1' seashore paspalum injury, seadhead count, and clipping yield following herbicide treatments in two combined greenhouse experiments, 2011, Griffin, GA.

Herbicide[a]	Rate	Injury		Seedhead count	Clipping yield
		2 WAT[b]	4 WAT	4 WAT	4 WAT
	kg ai ha^{-1}	——— % ———		——— % Reduction of untreated ———	
Atrazine	2.24	44	28	87	54
Bispyribac-sodium	0.11	21	29	97	69
Ethofumesate	1.68	3	7	55	39
Foramsulfuron	0.03	16	7	67	27
Pronamide	0.84	0	0	3	−4
	1.68	1	1	1	−4
	3.36	3	3	39	10
Rimsulfuron	0.04	16	12	94	36
Trifloxysulfuron	0.03	17	52	98	68
$LSD_{0.05}$		4	9	15	15

[a] Products applied in this experiment included Aatrex 4L (atrazine), Syngenta Corp. Greensboro, NC; Velocity 17.6SG (bispyribac-sodium), Valent Corp., Walnut Creek, CA; Prograss 1.5EC (ethofumesate), Bayer, Montvale, NJ; Kerb 50WP (pronamide), Dow Agrosciences, Indianapolis, IN; TranXit (rimsulfuron), and Monument (trifloxysulfuron) Syngenta Corp., Greensboro, NC.

[b] Abbreviation: WAT, weeks after treatment.

Greenhouse Experiments. Experiment-by-treatment interactions were not detected for injury, clipping yield, or seedhead suppression; therefore results were combined over experiments. Seashore paspalum injury from pronamide was minimal (5% or less) from all three pronamide treatments by 2 and 4 WAT, which is similar to field experiments (Table 3). Atrazine, bispyribac-sodium, and trifloxysulfuron injured seashore paspalum 28, 29, and 52% by 4 WAT, respectively. Injury from foramsulfuron and rimsulfuron was less severe than the aforementioned herbicides, ranging up to 16% by 2 WAT but declining to < 15% by 4 WAT. Ethofumesate injured seashore paspalum < 10% and was comparable with pronamide. Although injury from ethofumesate was minimal, practitioners have limited potential to control annual bluegrass in spring due to reductions in efficacy on mature populations (Coats and Krans 1996; Johnson 1983). Furthermore, ethofumesate has shown erratic levels of injury on seashore paspalum when applied alone or with other herbicides and warrants further investigation for use in spring to control annual bluegrass (Johnson and Duncan 2000; Unruh et al. 2006).

Seashore paspalum exhibited shoot growth reductions and seedhead suppression from most treatments. Pronamide at 0.84 and 1.68 kg ha^{-1} did not produce meaningful reductions in seedhead counts from the untreated but pronamide at 3.36 kg ha^{-1} reduced seedheads by 39% (Table 3). However, these results were significantly less than all other herbicides tested. Atrazine, bispyribac-sodium, rimsulfuron, and trifloxysulfuron reduced seedhead counts by 87 to 98% from the untreated, whereas ethofumesate and foramsulfuron reduced seedhead counts by 55 and 67%, respectively.

Pronamide at 0.84 and 1.68 kg ha^{-1} did not reduce seashore paspalum clippings compared with the untreated, whereas 3.36 kg ha^{-1} caused 10% reductions after 4 wk. Similar to seedhead count reductions, effects of pronamide on clipping yield were less substantial than other herbicides tested. Atrazine, bispyribac-sodium, and trifloxysulfuron reduced clippings by 54 to 69% from the untreated, whereas ethofumesate, foramsulfuron, and rimsulfuron reduced clippings by 27 to 39%.

Seedhead suppression and clipping yield reductions suggest that seashore paspalum could be sensitive to herbicides commonly used for annual bluegrass control in turfgrass. Pronamide appears to cause minimal injury to seashore paspalum but high rates (3.36 kg ha^{-1}) have potential for growth inhibition from the untreated. Seashore paspalum had the best tolerance to pronamide and ethofumesate but was most sensitive to atrazine and sulfonylureas. Previous research with triazine herbicide use on seashore paspalum is limited but further investigations are warranted to evaluate spring safety after dormant applications.

Sulfonylureas appear to have variable safety and activity at standard use rates on seashore paspalum but could have potential for managing clippings and seedheads. Sulfonylureas such as chlorsulfuron, metsulfuron, and sulfometuron-methyl may inhibit turfgrass growth at sublethal rates and can be used for growth regulation in management programs (Beyrouty et al. 1989; Hixson et al. 2007; Nelson et al. 1993; Spak et al. 1993). Monthly applications of flazasulfuron at 18 and 27 g ai ha^{-1} provided good (> 80%) seedhead suppression and clipping reductions on seashore paspalum during active growth but research with other sulfonylureas is limited (McCullough et al. 2011). Although sulfonylureas have potential to cause excessive injury during active growth, applications to dormant seashore paspalum could have potential to safely control annual bluegrass without inhibiting spring green-up; this warrants further investigation.

In conclusion, pronamide appears to be safe and effective for use on seashore paspalum during green-up, dormancy, or active growth in spring. Results from these experiments and previous research suggest that seashore paspalum may be excessively injured by POST herbicides commonly used for annual bluegrass control. Further research is needed to evaluate application rates and regimes of other herbicides to optimize seashore paspalum safety to treatments for annual bluegrass control.

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