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Postemergence Weed Control in Warm-season Turfgrass with a Mixture of Pyrimisulfan and Penoxsulam

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***Abstract*. Pyrimisulfan is a sulfonanilide herbicidal inhibitor of acetolactate synthase (ALS) used to control grass and sedge weeds of rice (*Oryza stricta* L.) production. Penoxsulam is an ALS-inhibiting herbicide that provides early postemergence control of broadleaf weeds in managed turfgrass. Separate field trials were conducted in Knoxville, TN, during Summer 2017 and 2018 to evaluate the efficacy of pyrimisulfan + penoxsulam for control of white clover (*Trifolium repens* L.), yellow nutsedge (*Cyperus esculentus* L.), wild violet (*Viola* spp.), ground ivy (*Glechoma hederacea* L.), and virginia buttonweed (*Diodia virginiana* L.) in common bermudagrass (*Cynodon dactylon* L.) and tall fescue (*Festuca arundinacea* Schreb.) turf. All treatments were applied on a granular fertilizer carrier (mean particle size, 1.5 mm) that contained 21% N : 0% P_2O_5 : 3% K_2O. Treatments were applied at an early postemergence growth stage during April of each year and were irrigated into the soil within 24 hours of application. Weed control was assessed from 4 to 10 weeks after initial treatment (WAIT) relative to untreated control plots in each replication. White clover and wild violet were controlled effectively with pyrimisulfan + penoxsulam at 70 + 70 g·ha^{-1} whereas sequential applications at either 70 + 70 g·ha^{-1} followed by 35 + 35 g·ha^{-1} or 52.5 + 52.5 g·ha^{-1} followed by 52.5 + 52.5 g·ha^{-1} were needed to control yellow nutsedge, ground ivy, and virginia buttonweed effectively. Future research should explore long-term control of these species, particularly wild violet, ground ivy, and virginia buttonweed with pyrimisulfan + penoxsulam applied over multiple seasons. Chemical names: 2′-[(4,6-dimethoxypyrimidin-2-yl)(hydroxy) methyl]-1,1-difluoro-6′-(methoxymethyl)methanesulfonanilide (pyrimisulfan); 2-(2,2-difluoroethoxy)-N-(5,8-dimethoxy1,2,4triazolo 1.5-c-pyrimidin-2-yl)-6-(trifluoromethyl) benzenesulfonamide (penoxsulam).**

Pyrimisulfan is a sulfonanilide herbicidal inhibitor of ALS with structural similarity to bispyribac-sodium and pyrithiobac-sodium (Asakura et al., 2012). Pyrimisulfan is used for both pre- and postemergence weed control in rice (*Oryza stricta* L.) paddy fields (Yoshimura et al., 2013). Applications of pyrimisulfan at 50 to 75 g·ha^{-1} effectively controlled *Echinochloa* spp., rock bulrush (*Schoenoplectus juncoides*), pickerel weed (*Monochoria vaginalis*), and *Lindernia* spp. in greenhouse trials (Asakura et al., 2012).

Reduced efficacy of pyrimisulfan formulated as a "wettable" powder under flooded conditions common in rice production spurred the development of a controlled-release granular formulation (0.67% pyrimisulfan) designed to control weeds both pre- and postemergence (Asakura et al., 2012). A series of greenhouse experiments were conducted in Japan to compare weed control efficacy of this controlled-release granular formulation to a granular formulation of bensulfuron-methyl (0.75%) + bromobutide (9%) + pentoxazone (2%) + pyriminobac-methyl (4.5%) that is a standard herbicide used by Japanese rice producers (Asakura et al., 2012). Herbicides were applied at 10 kg·ha^{-1} both pre- and postemergence with and without simulated flooding. Granular pyrimisulfan controlled 16 different weed species 96% to 100% when applied preemergence, including biotypes of pickerel weed and rock bulrush with target site resistance to sulfonylurea herbicides. Similarly, granular application of pyrimisulfan at an early postemergence timing (two to three leaves) controlled seven different weed species 90% to 100%, including two biotypes with confirmed resistance to sulfonylurea herbicides. Flooding did not affect efficacy of granular pyrimisulfan in either experiment whereas the standard of bensulfuron-methyl + bromobutide + pentoxazone + pyriminobac-methyl showed reduced efficacy for control of tidalmarsh flatsedge (*Cyperus serotinus* Rottb.), *Scirpus nipponicus* Makino, cosmopolitan bulrush [*Bolboschoenus maritimus* (L.) Palla], pigmy arrowhead (*Sagittaria pygmaea* Miq.), and threeleaf arrowhead (*Sagittaria trifolia* L.) under flooded conditions.

Penoxsulam is an ALS inhibitor used for broadleaf weed control in managed turfgrass systems (Loughner et al., 2006). Penoxsulam provides early postemergence control of weeds such as white clover (*Trifolium repens* L.), buckhorn plantain (*Plantago lanceolata* L.), common dandelion (*Taraxacum officinale* L.), ground ivy (*Glechoma hederacea* L.), and virginia buttonweed (*Diodia virginiana* L.) at rates of 20 to 180 g·ha^{-1} (Loughner et al., 2006). Interestingly, weed control efficacy of penoxsulam applied on a granular fertilizer carrier (average particle size, 0.5–2.5 mm) exceeded applications formulated as liquids (Loughner et al., 2006). Penoxsulam is often applied in combination with other herbicides to widen the spectrum of weeds controlled by a single application. For example, Loughner and Nolting (2010) evaluated efficacy of penoxsulam + 2,4-D + dicamba (LockUp; Dow AgroSciences, Indianapolis, IN) for control of white clover and common dandelion at six locations in the northern United States over 2 years. The researchers found that the presence of foliar moisture at application increased efficacy. Synergy has been observed when combining penoxsulam with other ALS-inhibiting herbicides as well (Hufnagl and Mann, 2015).

Weed control efficacy of granular pyrimisulfan is limited to grassy weed and tuber species of rice (Asakura et al., 2012). Penoxsulam is an effective option for early-postemergence control of broadleaf weeds (Loughner et al., 2006). Considering that both pyrimisulfan and penoxsulam efficacy are improved when applied on a granular carrier, combining pyrimisulfan with penoxsulam may provide turfgrass managers a new option for broadleaf and sedge weed control in warm-season turfgrass. Hoyle (2017) reported that pyrimisulfan + penoxsulam was safe for use on both buffalograss (*Bouteloua dactyloides*, cv. Cody) and zoysiagrass (*Zoysia japonica*, cv. Meyer), and effectively controlled large crabgrass (*Digitaria sanguinalis*). However, there are no published reports on sedge and broadleaf weed control efficacy of pyrimisulfan + penoxsulam in warm-season turfgrass. We hypothesized that pyrimisulfan + penoxsulam could effectively control white clover, yellow nutsedge, wild violet (*Viola* spp.), ground ivy, and virginia buttonweed when applied at an early-postemergence growth stage. Several field experiments were conducted during 2017 and 2018 to test this hypothesis.

Materials and Methods

Research sites. Field trials were conducted at the East Tennessee AgResearch and Education Center – Plant Sciences Unit, Knoxville, TN, from Apr. through Aug. 2017 and 2018. All trials were conducted in areas of common bermudagrass (*Cynodon dactylon* L.) or tall fescue (*Festuca arundinacea* Schreb.) turf established on Sequatchie silt loam soil (fine-loamy, siliceous, semi-active, thermic humic Hapludult) with pH values ranging from 5.7 to 6.7. Separate sites were used to evaluate treatment efficacy vs. natural infestations of white clover, yellow

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nutsedge, and virginia buttonweed; however, wild violet and ground ivy data were collected from a single site containing a mixed population of both species. Each year virginia buttonweed data were collected from a Riviera common bermudagrass fairway maintained at a 1.5-cm mowing height with a reel-mower (Reelmaster 5500D; The Toro Co., Bloomington, MN). Wild violet and ground ivy data were collected from a stand of tall fescue utility turf maintained at 8 cm with a rotary mower (Gravely 260Z; Gravely Tractor, Brillion, WI). White clover and yellow nutsedge data were collected from mixed stands of common bermudagrass and tall fescue maintained at 6 to 8 cm with the same aforementioned rotary mower. Irrigation was applied to supplement rainfall at all trial sites except the one used to collect wild violet and ground ivy data; this location received rainfall only.

White clover control. Treatments evaluated for control of white clover included pyrimisulfan + penoxsulam (EH1580; PBI Gordon Corporation, Kansas City, MO) at 35 + 35 $g \cdot ha^{-1}$ or 70 + 70 $g \cdot ha^{-1}$, as well as an untreated check. Both pyrimisulfan and penoxsulam were impregnated on a granular fertilizer at 0.025% (total herbicide load = 0.05%). The analysis of the fertilizer used for impregnation was 21% N : 0% P_2O_5 : 3% K_2O, with N included in the form of polymer-coated urea. Fertilizer particle size averaged 1.5 mm. Treatments were applied on 26 Apr. 2017 and 25 Apr. 2018 using a shaker jar. Experimental design was a randomized complete block with four replications of plots measuring 1.5 × 1.8 m in 2017 and 1.5 × 1.5 m in 2018. All treatments were irrigated into the soil within 24 h of application.

Yellow nutsedge control. Treatments evaluated for control of yellow nutsedge included pyrimisulfan + penoxsulam at 35 + 35 $g \cdot ha^{-1}$ or 70 + 70 $g \cdot ha^{-1}$ applied singly, as well as sequential applications of 70 + 70 $g \cdot ha^{-1}$ followed by 35 + 35 $g \cdot ha^{-1}$ or 52.5 + 52.5 $g \cdot ha^{-1}$ followed by 52.5 + 52.5 $g \cdot ha^{-1}$. An untreated check was included for comparison each year. Treatments were applied on the aforementioned granular fertilizer carrier on 26 Apr. 2017 and 25 Apr. 2018 using a shaker jar. Sequential applications were made with the same equipment on 30 May 2017 and 6 June 2018. Experimental design was a randomized complete block with four replications of plots measuring 1.5 × 1.8 m in 2017 and 1.5 × 2.1 m in 2018. All treatments were irrigated into the soil within 24 h of application.

Wild violet and ground ivy control. Herbicide treatments evaluated on yellow nutsedge were also assessed for wild violet and ground ivy control each year. Treatments were applied on the aforementioned granular fertilizer carrier on 4 Apr. 2017 and 25 Apr. 2018 using a shaker jar. Sequential applications were made with the same equipment on 26 Apr. 2017 and 24 May 2018. Experimental design was a randomized complete block with four replications of plots measuring 1.5 × 1.8 m in 2017 and 1.5 × 1.5 m in 2018. Rainfall occurred within 24 h of treatment application to move herbicides into the soil.

Virginia buttonweed control. Treatments evaluated for control of virginia buttonweed included pyrimisulfan + penoxsulam at 70 + 70 $g \cdot ha^{-1}$ applied singly, as well as sequential applications of 70 + 70 $g \cdot ha^{-1}$ followed by 35 + 35 $g \cdot ha^{-1}$ or 52.5 + 52.5 $g \cdot ha^{-1}$ followed by 52.5 + 52.5 $g \cdot ha^{-1}$. An untreated check was included for comparison each year. Treatments were applied on the aforementioned granular fertilizer carrier on 26 Apr. 2017 and 26 Apr. 2018 using a shaker jar. Sequential applications were made with the same equipment on 30 May 2017 and 24 May 2018. Experimental design was a randomized complete block with four replications of plots measuring 1.5 × 1.8 m in both 2017 and 2018. All treatments were irrigated into the soil within 24 h of application.

Data collection and statistical analysis. In all studies, weed control was evaluated on a 0% (i.e., no control) to 100% (i.e., complete kill) scale relative to untreated check plots in each replication at 4 to 10 WAIT. On each date that weed control data were collected, turfgrass injury was assessed using a similar percentage-based scale relative to untreated check plots. Analysis of variance was conducted in R (version 3.5.1) with data from each weed species analyzed separately. No statistically significant year-by-treatment interactions were detected in white clover, yellow nutsedge, wild violet, and virginia buttonweed control data. Therefore, means from each year were combined and separated using Fisher's protected least significant difference (LSD) test at the 0.05 level via the LSD.test function of the Agricolae package within R. Significant year-by-treatment interactions were detected in ground ivy control data, resulting in data from each year being analyzed and presented separately.

Results and Discussion

White clover control. Significant differences in white clover control resulting from herbicide treatment were detected at 4 to 10 WAIT (Table 1). Application of pyrimisulfan + penoxsulam at 70 + 70 $g \cdot ha^{-1}$ controlled white clover greater than 35 + 35 $g \cdot ha^{-1}$ on all assessment dates. Overall white clover control with a single application of pyrimisulfan + penoxsulam at 70 + 70 $g \cdot ha^{-1}$ ranged from 96% to 100% compared with 69% to 87% for 35 + 35 $g \cdot ha^{-1}$. Responses on white clover in the current study support those reported by Loughner et al. (2006), with penoxsulam applied alone at 140 $g \cdot ha^{-1}$. However, when penoxsulam was applied at 22 $g \cdot ha^{-1}$ in combination with 2,4-D and dicamba, white clover control only ranged from 44% to 71% at six locations in the northern United States (Loughner and Nolting, 2010). In addition to herbicidal efficacy, white clover control following application of pyrimisulfan + penoxsulam in the current study was also likely influenced by supplemental N delivered by these treatments. Application of pyrimisulfan + penoxsulam at 35 + 35 and 70 + 70 $g \cdot ha^{-1}$, delivered 29 and 59 $kg \cdot ha^{-1}$ N, respectively, in the form of polymer-coated urea. Reductions in broadleaf weed cover, particularly white clover, resulting from the application of N have been reported in tall fescue turf (Voigt et al., 2001).

Yellow nutsedge control. Significant differences in yellow nutsedge control resulting from herbicide treatment were detected at 4 to 10 WAIT (Table 2). Similar to observations on white clover, a single application of pyrimisulfan + penoxsulam at 70 + 70 $g \cdot ha^{-1}$ controlled yellow nutsedge greater than treatment at 35 + 35 $g \cdot ha^{-1}$ in this study. However, efficacy of single applications declined from 6 to 10 WAIT for both rates. For example, a single application of pyrimisulfan + penoxsulam at 35 + 35 $g \cdot ha^{-1}$ controlled yellow nutsedge 91% at 6 WAIT, but only 61% by 10 WAIT; a similar trend was observed for the 70 + 70 $g \cdot ha^{-1}$ application rate, with control measuring 98% at 6 WAIT and only 73% by 10 WAIT. This decline in yellow nutsedge control was not observed when pyrimisulfan + penoxsulam was applied sequentially. Both sequential application treatments controlled yellow nutsedge ≥99% by 10 WAIT. These responses support previous reports of pyrimisulfan effectively controlling *Cyperaceae* species, particularly

Table 1. White clover (*Trifolium repens* L.) control with single applications of pyrimisulfan and penoxsulam in Knoxville, TN. Means were combined from data collected during Summer 2017 and 2018.

		White clover control[y]			
Herbicide[z]	Rate ($g \cdot ha^{-1}$)	4 WAIT (%)	6 WAIT (%)	8 WAIT (%)	10 WAIT (%)
Pyrimisulfan + penoxsulam	35 + 35	87	79	79	69
	70 + 70	97	100	100	96
$LSD_{0.05}$		7	14	11	25

[z]Herbicides were impregnated on a fertilizer at 0.025% (total active ingredient load = 0.05%). The analysis of the fertilizer used for impregnation was 21% N : 0% P_2O_5 : 3% K_2O, with N included in the form of polymer-coated urea. Fertilizer particle size averaged 1.5 mm. Treatments were applied on 26 Apr. 2017 and 25 Apr. 2018 using a shaker jar. Application of pyrimisulfan + penoxsulam at 35 + 35 and 70 + 70 $g \cdot ha^{-1}$ delivered 29 and 59 $kg \cdot ha^{-1}$ N, respectively.
[y]White clover control assessed on a 0% (i.e., no control) to 100% (i.e., complete kill) scale relative to untreated check plots in each replication.
WAIT = weeks after initial treatment; LSD = least significant difference.

tidalmarsh flatsedge (Asakura et al., 2012). Reports of penoxsulam efficacy for postemergence yellow nutsedge control have been mixed. Loughner et al. (2006) reported only 35% to 65% yellow nutsedge control with penoxsulam applications in turfgrass; however, Tehranchian et al. (2015) reported ≈90% yellow nutsedge growth reduction after applying penoxsulam (40 g·ha^{-1}) to tubers (from a crop production field) in a greenhouse study. Nevertheless, our data indicate that a mixture of pyrimisulfan + penoxsulam may provide turfgrass managers an effective option for yellow nutsedge control compared with penoxsulam alone.

Wild violet control. Significant differences in wild violet control resulting from herbicide treatment were detected at 4 to 8 WAIT in this study (Table 3). Treatment with pyrimisulfan + penoxsulam at 35 + 35 g·ha^{-1} was ineffective (≤51% control); however, increasing the application rate to 70 + 70 g·ha^{-1} markedly increased control to 89% to 91% at 4 to 8 WAIT. There were no significant differences in wild violet control between a single application at 70 + 70 g·ha^{-1} and either sequential application regime evaluated. It should be noted that previous research has reported minimal effects of supplemental N on wild violet in tall fescue turf (Gray and Call, 1993); therefore responses observed in the current study were likely predominately the result of herbicidal efficacy and not the 29 to 59 kg·ha^{-1} N provided with applications of pyrimisulfan + penoxsulam in this study. In addition, although excellent efficacy was observed with pyrimisulfan + penoxsulam in this study, plots were only monitored for a limited time after application. Future research should explore long-term control of *Viola* spp. following treatment with pyrimisulfan + penoxsulam singly and sequentially.

Ground ivy control. Significant year-by-treatment interactions were detected in ground ivy control data (Table 4). In 2017, no significant differences in ground ivy control were detected among treatments at 6 or 8 WAIT. Overall control with single and sequential applications of pyrimisulfan + penoxsulam ranged from 70% to 100%.

In 2018, the 35 + 35 g·ha^{-1} rate of pyrimisulfan + penoxsulam was ineffective vs. ground ivy (≤28% control); increasing the application rate of pyrimisulfan + penoxsulam to 70 + 70 g·ha^{-1} markedly improved ground ivy control at both 6 and 8 WAIT. Sequential applications of pyrimisulfan + penoxsulam were highly effective in both years of the study, controlling ground ivy 93% to 100% in 2017 and 89% to 95% in 2018. These findings support reports by Patton et al. (2017) that ALS-inhibiting herbicides can be used to control ground ivy effectively. Moreover, the fertilizer carrier used to apply pyrimisulfan + penoxsulam in these studies may have affected ground ivy

Table 2. Yellow nutsedge (*Cyperus esculentus* L.) control with single and sequential applications of pyrimisulfan and penoxsulam in Knoxville, TN. Means were combined from data collected during Summer 2017 and 2018.

		Yellow nutsedge control[y]			
Herbicide[z]	Rate (g·ha^{-1})	4 WAIT (%)	6 WAIT (%)	8 WAIT (%)	10 WAIT (%)
Pyrimisulfan + penoxsulam	35 + 35	87	91	81	61
	70 + 70	96	98	96	73
	70 + 70 fb 35 + 35	95	99	100	100
	52.5 + 52.5 fb 52.5 + 52.5	96	100	100	99
$LSD_{0.05}$		8	5	9	23

[z]Herbicides were impregnated on a fertilizer at 0.025% (total active ingredient load = 0.05%). The analysis of the fertilizer used for impregnation was 21% N : 0% P_2O_5 : 3% K_2O, with N included in the form of polymer-coated urea. Fertilizer particle size averaged 1.5 mm. Treatments were applied on 26 Apr. 2017 and 25 Apr. 2018 using a shaker jar. Sequential applications were made with the same equipment on 30 May 2017 and 6 June 2018. Application of pyrimisulfan + penoxsulam at 35 + 35, 70 + 70, and 52.5 + 52.5 g·ha^{-1} delivered 29, 59, and 44 kg·ha^{-1} N, respectively.
[y]Yellow nutsedge control assessed on a 0% (i.e., no control) to 100% (i.e., complete kill) scale relative to untreated check plots in each replication.
WAIT = weeks after initial treatment; fb = followed by; LSD = least significant difference.

Table 3. Wild violet (*Viola* spp.) control with pyrimisulfan and penoxsulam applications in Knoxville, TN. Means were combined from data collected during Summer 2017 and 2018.

		Wild violet control[y]		
Herbicide[z]	Rate (g·ha^{-1})	4 WAIT (%)	6 WAIT (%)	8 WAIT (%)
Pyrimisulfan + penoxsulam	35 + 35	51	37	31
	70 + 70	92	89	91
	70 + 70 fb 35 + 35	94	97	97
	52.5 + 52.5 fb 52.5 + 52.5	86	97	84
$LSD_{0.05}$		20	21	29

[z]Herbicides were impregnated on a fertilizer at 0.025% (total active ingredient load = 0.05%). The analysis of the fertilizer used for impregnation was 21% N : 0% P_2O_5 : 3% K_2O, with N included in the form of polymer-coated urea. Fertilizer particle size averaged 1.5 mm. Treatments were applied on 4 Apr. 2017 and 25 Apr. 2018 using a shaker jar. Sequential applications were made with the same equipment on 26 Apr. 2017 and 24 May 2018. Application of pyrimisulfan + penoxsulam at 35 + 35, 70 + 70, and 52.5 + 52.5 g·ha^{-1} delivered 29, 59, and 44 kg·ha^{-1} N, respectively.
[y]Wild violet control assessed on a 0% (i.e., no control) to 100% (i.e., complete kill) scale relative to untreated check plots in each replication.
WAIT = weeks after initial treatment; fb = followed by; LSD = least significant difference.

Table 4. Ground ivy (*Glechoma hederacea* L.) control with pyrimisulfan and penoxsulam applications in Knoxville, TN, during Summer 2017 and 2018.

		Ground ivy control[y]			
		2017		2018	
Herbicide[z]	Rate (g·ha^{-1})	6 WAIT (%)	8 WAIT (%)	6 WAIT (%)	8 WAIT (%)
Pyrimisulfan + penoxsulam	35 + 35	70	85	28	15
	70 + 70	83	93	83	75
	70 + 70 fb 35 + 35	100	100	94	95
	52.5 + 52.5 fb 52.5 + 52.5	93	95	89	93
$LSD_{0.05}$		NS	NS	17	24

[z]Herbicides were impregnated on a fertilizer at 0.025% (total active ingredient load = 0.05%). The analysis of the fertilizer used for impregnation was 21% N : 0% P_2O_5 : 3% K_2O, with N included in the form of polymer-coated urea. Fertilizer particle size averaged 1.5 mm. Treatments were applied on 4 Apr. 2017 and 25 Apr. 2018 using a shaker jar. Sequential applications were made with the same equipment on 26 Apr. 2017 and 24 May 2018. Application of pyrimisulfan + penoxsulam at 35 + 35, 70 + 70, and 52.5 + 52.5 g·ha^{-1} delivered 29, 59, and 44 kg·ha^{-1} N, respectively.
[y]Ground ivy control assessed on a 0% (i.e., no control) to 100% (i.e., complete kill) scale relative to untreated check plots in each replication
WAIT = weeks after initial treatment; fb = followed by; LSD = least significant difference; NS = not significant.

Table 5. Virginia buttonweed (*Diodia virginiana* L.) control with pyrimisulfan and penoxsulam applications in Knoxville, TN. Means were combined from data collected during Summer 2017 and 2018.

Herbicide[z]	Rate (g·ha^{-1})	Virginia buttonweed control[y] 4 WAIT (%)	6 WAIT (%)	8 WAIT (%)	10 WAIT (%)
Pyrimisulfan + penoxsulam	70 + 70	85	70	63	53
	70 + 70 fb 35 + 35	83	94	83	87
	52.5 + 52.5 fb 52.5 + 52.5	81	89	79	76
$LSD_{0.05}$		NS	14	NS	18

[z]Herbicides were impregnated on a fertilizer at 0.025% (total active ingredient load = 0.05%). The analysis of the fertilizer used for impregnation was 21% N : 0% P_2O_5 : 3% K_2O, with N included in the form of polymer-coated urea. Fertilizer particle size averaged 1.5 mm. Treatments were applied on 26 Apr. 2017 and 26 Apr. 2018 using a shaker jar. Sequential applications were made with the same equipment on 30 May 2017 and 24 May 2018. Application of pyrimisulfan + penoxsulam at 35 + 35, 70 + 70, and 52.5 + 52.5 g·ha^{-1} delivered 29, 59, and 44 kg·ha^{-1} N, respectively.

[y]Virginia buttonweed control assessed on a 0% (i.e., no control) to 100% (i.e., complete kill) scale relative to untreated check plots in each replication.

WAIT = weeks after initial treatment; fb = followed by; LSD = least significant difference; NS = not significant.

control positively. Herbicides were applied on a fertilizer carrier that included 21% N in the form of polymer-coated urea. To that end, applications of pyrimisulfan + penoxsulam at 70 + 70 g·ha^{-1} delivered 59 kg·ha^{-1} N. Improvements in ground ivy control when combining herbicide applications with N fertilizer have been reported previously (Kohler et al., 2004).

Virginia buttonweed control. Similar to what was observed for ground ivy, significant differences in virginia buttonweed control were detected among treatments, with sequential applications of pyrimisulfan + penoxsulam improving control compared with applying these herbicides singly (Table 5). A single application of pyrimisulfan + penoxsulam at 70 + 70 g·ha^{-1} controlled virginia buttonweed 85% at 4 WAIT, but declined to 53% by 10 WAIT. Comparatively, both sequential applications resulted in 76% to 87% virginia buttonweed control by 10 WAIT with no significant differences detected between the 70 + 70 g·ha^{-1} followed by 35 + 35 g·ha^{-1} or the 52.5 + 52.5 g·ha^{-1} followed by 52.5 + 52.5 g·ha^{-1} treatments. Overall, virginia buttonweed control with pyrimisulfan + penoxsulam could be improved by applying treatments sequentially over multiple seasons, as has been shown with auxin herbicides including 2,4-D, mecoprop, and dicamba in warm-season turfgrass (Kelly and Coats, 2000). Future research should explore this concept in further detail.

Overall results of this research highlight that pyrimisulfan + penoxsulam may provide turfgrass managers a new option for managing sedge and broadleaf weeds of warm-season turfgrass systems. This is significant given that granular herbicides offer many advantages to turfgrass managers, including reduced application equipment costs and minimal concern over pesticide drift (Christians et al., 2017). Moreover, there are few effective granular herbicide options in turfgrass with most active ingredients performing optimally when formulated as liquids (Patton and Weisenberger, 2012). However, active ingredients such as penoxsulam and pyrimisulfan that can enter susceptible weeds via root tissue (Senseman, 2007; D. Sanson, personal communication) can provide effective weed control similar to liquid formulations (Patton and Weisenberger, 2012).

No turfgrass injury was observed in any of the aforementioned experiments (data not presented), which aligns with previous reports by Hoyle (2017). However, we did not explore tolerance of cool-season species such perennial ryegrass (*Lolium perenne* L.) to pyrimisulfan + penoxsulam in this research. When applied alone, penoxsulam can be used to suppress overseeded stands of perennial ryegrass from bermudagrass (*Cynodon* spp.) golf courses and sports fields (Anonymous, 2014). Given that cool-season turfgrass golf courses, sports fields, and lawns often contain mixtures of *Festuca*, *Lolium*, and *Poa* species, use of pyrimisulfan + penoxsulam may be better suited for warm-season turfgrass systems of the southern United States. However, additional research on cool-season turfgrass tolerance to pyrimisulfan + penoxsulam, as well as pyrimisulfan alone, is warranted. Furthermore, reports of sulfonylurea herbicides selecting for ALS resistance in both broadleaf weed and sedge species of warm-season turfgrass (McCullough et al., 2016a, 2016b) warrants further research on efficacy of pyrimisulfan + penoxsulam for managing these resistant biotypes.

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