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Control of Summer Annual Grasses during Seeded Zoysiagrass Establishment with Various Timings and Rates of Fluazifop, Triclopyr, and Fluazifop plus Triclopyr

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Summer annual grasses such as goosegrass and smooth crabgrass can hinder seeded zoysiagrass establishment. The herbicide fluazifop controls various grassy weed species but can injure mature and seedling zoysiagrass. Research has indicated that fluazifop applications can be safened on mature zoysiagrass cultivars with the addition of triclopyr. Based on these observations, research was conducted to evaluate weed control and tolerance of seeded 'Zenith' zoysiagrass to fluazifop (0.11 or 0.21 kg ai ha^{-1}), triclopyr (1.12 kg ae ha^{-1}), or fluazifop plus triclopyr (0.11 or 0.21 kg ha^{-1} plus 1.12 kg ha^{-1}) applied at seeding, 14, or 28 d after emergence (DAE). All herbicide treatments applied at seeding did not hinder zoysiagrass germination but did not reduce goosegrass populations. Fluazifop alone (0.11 and 0.21 kg ha^{-1}) applied at 14 and 28 DAE injured zoysiagrass seedlings but was reduced with the addition of triclopyr. At the end of the growing season, the greatest zoysiagrass cover was achieved by applications of fluazifop alone (0.11 kg ha^{-1}) applied at 14 DAE or fluazifop (0.11 or 0.21 kg ha^{-1}) plus triclopyr applied at 14 or 28 DAE. Fluazifop (0.11 or 0.21 kg ha^{-1}) applied alone or tank-mixed with triclopyr controlled goosegrass $>$ 70% when applied 14 and 28 DAE. Based on these data, applications of fluazifop tank-mixed with triclopyr can successfully control goosegrass without injuring Zenith zoysiagrass seedlings.

Nomenclature: Fluazifop-P, (R)-2-[4-[[5-(trifluoromethyl)-2-pyridinyl]oxy]phenoxy]propanoic acid; siduron, N-(2-methylcyclohexyl)-N9-phenylurea; triclopyr, [(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid; goosegrass, *Eleusine indica* (L.) Gaertn.; smooth crabgrass, *Digitaria ischaemum* (Schreb.) Schreb. ex Muhl.; zoysiagrass, *Zoysia japonica* Steud. 'Zenith'.

Key words: Safens, tank-mixture, weed control, zoysiagrass seedlings.

Los zacates anuales de verano como *Eleusine indica* y *Digitaria ischaemum* pueden inhibir el establecimiento de *Zoysia japonica.* El herbicida fluazifop controla varias especies de gramíneas pero puede dañar a *Z. japonica*, tanto en estado de plántula como en estado adulto. Investigaciones han indicado que las aplicaciones de fluazifop pueden ser seguras en cultivares de *Z. japonica* adultos con la adición de triclopyr. En base a estas observaciones, se realizó una investigación para evaluar el control de malezas y la tolerancia de la variedad 'Zenith'de *Z. japonica* al fluazifop (0.11 ó 0.21 kg ia ha^{-1}), al triclopyr (1.12 kg ea ha^{-1}), o al fluazifop más triclopyr (0.11 ó 0.21 kg ha^{-1} más 1.12 kg ha^{-1}) aplicados en la siembra, 14 ó 28 días después de la emergencia (DAE). Todos los tratamientos de herbicidas aplicados en la siembra no impidieron la germinación de *Z. japonica,* pero tampoco redujeron las poblaciones de *E. indica.* Fluazifop solo (0.11 y 0.21 kg ha^{-1}), aplicado a los 14 ó 28 DAE, dañó las plántulas de *Z. japonica* pero el daño se redujo con la adición de triclopyr. Al final del ciclo de cultivo, se logró la mayor cobertura de *Z. japonica* con aplicaciones de fluazifop solo (0.11 ó 0.21 kg ha^{-1}) a los 14 DAE, o fluazifop (0.11 ó 0.21 kg ha^{-1}) más triclopyr aplicado a los 14 ó 28 DAE. Fluazifop (0.11 ó 0.21 kg ha^{-1}) aplicado solo o mezclado con triclopyr controló *E. indica* $>$ 70% cuando se aplicó a los 14 y 28 DAE. Con base en esta información, las aplicaciones de fluazifop mezclado con triclopyr pueden controlar *E. indica* exitosamente sin dañar las plántulas de *Z. japonica* variedad 'Zenith'.

Zoysiagrass is a warm-season turfgrass well adapted for use on golf course fairways in the transitional climatic zone (Beard 1973). Traditional zoysiagrass establishment required vegetative propagation making zoysiagrass an overlooked fairway turfgrass due to the slow establishment rate from sprigging or the high cost associated with sodding. Research indicates more than two growing seasons are required to establish sprigged 'Meyer' zoysiagrass (*Zoysia japonica* Steud.) into a uniform turfgrass stand (Carroll et al. 1996). Sprigging zoysiagrass cost $\geq$ \$7,500 per hectare and can require 2 to 3 yr until complete turfgrass coverage is achieved (Patton et al. 2006). Sodding zoysiagrass produces an instant turfgrass cover, but plant material and instillation cost can range $\geq$ \$40,000 per hectare (Patton et al. 2006).

Many of the first available seeded zoysiagrass cultivars have poor seed germination rates and unacceptable turf quality (Patton et al. 2006). However, the commercially available cultivar Zenith zoysiagrass (*Z. japonica* Steud.) has high seed germination rates and quality comparable to Meyer zoysiagrass (NTEP 2007). Furthermore, establishing seeded Zenith zoysiagrass has agronomic and economic advantages to sprigging or sodding other zoysiagrass cultivars, because $\geq$ 90% turfgrass cover can be achieved in one growing season, and establishment costs are reduced to \$2,200 per hectare (Patton et al. 2004a, 2006; Zuk and Fry 2005).

Controlling weed competition during seeded zoysiagrass establishment is necessary to expedite turfgrass development (Carroll et al. 1996; Johnson 1976). Failure to control perennial weeds prior to establishment and summer annuals

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after germination can significantly reduce zoysiagrass cover (Patton et al. 2004b). The use of herbicides for weed control during early establishment of warm-season turfgrasses is critical to their winter survival (Bingham and Shaver 1981). Establishing seeded zoysiagrass is recommended during early spring and summer. However, this timing coincides with the germination of difficult to control summer annual grasses, including crabgrass (*Digitaria* spp.) and goosegrass (Patton et al. 2004b).

Numerous herbicides are labeled for grassy and broadleaf weed control in established zoysiagrass, but few are labeled for use in seedling zoysiagrass (Patton et al. 2007). PRE siduron applications effectively control annual grassy weeds with minimal phytotoxic injury to seeded zoysiagrass (Portz et al. 1981). Unfortunately, siduron does not control goosegrass or provide season-long crabgrass control (Anonymous 2004a; Dernoeden 1984). Fluazifop is an aryloxyphenoxypropionate (AOPP) herbicide labeled for the POST control of grassy weed species in established zoysiagrass (Anonymous 2004b). However, fluazifop (0.07 kg ha^{-1}) has been reported to injure and reduce Zenith zoysiagrass seedling cover when applied 4 wk after emergence (WAE) (Patton et al. 2007). Triclopyr is a synthetic auxin herbicide labeled for POST broadleaf weed control in zoysiagrass turf (Anonymous 2008). Research has indicated tank-mixing fluazifop with triclopyr reduced injury to established 'Cavalier' [*Zoysia matrella* (L.) Merr.], Meyer, 'Palisades' (*Z. japonica*), and Zenith zoysiagrass cultivars (Lewis et al. 2010; McElroy and Breeden 2006). Based on these observations, research was conducted to evaluate weed control and tolerance of seeded Zenith zoysiagrass to fluazifop, triclopyr, or fluazifop plus triclopyr at various rates and application timings.

Materials and Methods

Experiments were initiated on May 24, 2007, and May 12, 2008, at the University of Tennessee East Tennessee Research and Education Center—Plant Sciences Unit in Knoxville, Tennessee. Soil type is a Sequatchie loam soil (Fine-loamy, siliceous, semiactive, thermic Humic Hapludult) with pH of 6.2 and 2.1% organic matter content. Soil was tilled and amended with a starter fertilizer (LESCO® 18-24-12 Professional Starter Fertilizer, LESCO, Inc. Service Center, East Syracuse, NY 13057-2943) applied at 50 kg N ha^{-1}. The test area was rolled to provide a smooth seed bed. Prior to seeding, a PRE siduron (Turpersan® herbicide, PBI Gordon Corporation, Kansas City, MO 64101) application (6.7 kg ha^{-1}) was applied to the test area to reduce crabgrass incidence during zoysiagrass germination. Zenith zoysiagrass was seeded at 52.75 kg ha^{-1} and covered with germination blankets for 10-d period to prevent seed movement and maintain adequate moisture. Following removal of the germination blanket, the test area was initially mowed with a rotary mower (7.6 cm height-of-cut) and gradually lowered to fairway height (1.2 cm height-of-cut) with a reel mower. For the duration of the study, plots were managed as a golf course fairway with regard to fertility (151 kg N ha^{-1} per growing season), mowing (3 times weekly), and irrigation (supplementary to natural rainfall).

Herbicide treatments included two rates of fluazifop (Fusilade II® herbicide, Syngenta Crop Protection, Inc., Greensboro, NC 27409) (0.11 or 0.21 kg ai ha^{-1}) applied alone or tank-mixed with triclopyr (Turflon Ester® herbicide, Dow AgroScience, Indianapolis, IN 46268) (1.12 kg ae ha^{-1}). Applications timings included treatments applied at seeding, 14 DAE, or 28 DAE. Zenith zoysiagrass averaged two to three and five to seven leaves at 14 and 28 DAE, respectively, and goosegrass averaged three to five and five to eight leaves at 14 and 28 DAE, respectively. All herbicide treatments and application timings were compared to nontreated plots. Herbicide treatments were applied with a nonionic surfactant (Latron AG-98™ nonionic surfactant [alkylaryl polyoxyethlene glycols, nonylphenoxypolyethoxyethanon, and n-butanol], Rohm and Haas Co., Philadelphia, PA 19106) at 0.25% v/v ratio in a water carrier volume of 280 L ha^{-1}. Applications were made with a CO_2-pressurized sprayer boom which employed four TeeJet (TeeJet® XR11002VS spraying nozzles, Spraying Systems Co., Wheaton, IL 60189) 11002 XR flat-fan nozzles on 24-cm spacings at 276 kPa.

The experimental design was a randomized complete block design of four replicates with individual plots measuring 1.5 by 1.5 m. In both experimental runs, natural populations of carpetweed (*Mollugo verticillata* L.), goosegrass, and smooth crabgrass were evaluated for control. Visual evaluations of percent Zenith zoysiagrass seedling injury and percent weed control were taken every 14 DAE and evaluated relative to the nontreated on a 0 to 100% scale (0% = no visible injury or no population reduction; 100% = complete population death). At 98 DAE, the line intersect method was used to determine percent cover of Zenith zoysiagrass and goosegrass (Gaussoin and Branham 1989). The line intersect grid was constructed of plastic wire lines spaced at 10-cm centers on a metal frame (90 cm by 110 cm) creating 99 total intersects. Once the grid was laid on a plot, the plant material located under each intersect was recorded as an individual count to record total plant cover (0 to 99 scale).

Analysis of variance (P = 0.05) was conducted using MIXED model methodology (SAS 2004) and analyzed as a randomized complete block design in a factorial treatment arrangement (three application timings by two fluazifop rates by two triclopyr rates). Experimental run was designated as a random effect to allow the comparison of treatment means and interactions over multiple years and environmental conditions (Carmer et al. 1989; Lewis et al. 2010). Application timing by fluazifop rate by triclopyr rate was evaluated to determine if there was an interaction. Mean separation was conducted using Fisher's protected LSD ($P \leq 0.05$) and highest order interactions are reported.

Results and Discussion

PRE siduron application did not impede zoysiagrass emergence, similar to observations of Portz et al. (1981). Siduron controlled smooth crabgrass > 95% for the study duration, in contrast to results of Dernoeden (1984), who reported a single PRE siduron application did not provide season-long crabgrass control. The high level of crabgrass control could be due to minimal crabgrass pressure in both

Table 1. Zenith zoysiagrass injury and goosegrass control affected by an application timing by fluazifop rate by triclopyr rate interaction 28 and 42 DAE.[a]

Application timing (DAE)	Herbicide treatment[b]	Herbicide rate	Zoysiagrass 28 DAE	Zoysiagrass 42 DAE	Zoysiagrass 98 DAE	Goosegrass 28 DAE
		kg ha^{-1}[c]	% Injury[d]	% Injury[d]	Cover[e]	% Control[d]
Seeding	Fluazifop	0.11	0	0	75	0
Seeding	Fluazifop	0.21	0	0	69	0
Seeding	Triclopyr	1.12	0	0	72	0
Seeding	Fluazifop + triclopyr	0.11 + 1.12	0	0	65	0
Seeding	Fluazifop + triclopyr	0.21 + 1.12	0	0	67	0
14	Fluazifop	0.11	12	1	83	72
14	Fluazifop	0.21	13	5	69	76
14	Triclopyr	1.12	1	0	73	48
14	Fluazifop + triclopyr	0.11 + 1.12	7	0	87	83
14	Fluazifop + triclopyr	0.21 + 1.12	7	1	91	81
28	Fluazifop	0.11	—	12	76	—
28	Fluazifop	0.21	—	16	76	—
28	Triclopyr	1.12	—	4	72	—
28	Fluazifop + triclopyr	0.11 + 1.12	—	6	93	—
28	Fluazifop + triclopyr	0.21 + 1.12	—	9	88	—
—	Nontreated	—	—	0	74	0
$LSD_{(< 0.01)}$			2	4	11	9

[a] Abbreviation: DAE, days after emergence.

[b] A nonionic surfactant was included with each treatment at 0.25% v/v.

[c] Fluazifop displayed as kg ai ha^{-1}; triclopyr displayed as kg ae ha^{-1}.

[d] Evaluated visually on a 0 to 100% scale, based on a 0 = no injury/control and 100 = complete plant death.

[e] Evaluated using the line intersect method on a 0 to 99 scale.

trial locations, because each was converted from established tall fescue [*Lolium arundinaceum* (Schreb.) S. J. Darbyshire] stands which received PRE crabgrass control applications in years prior to experiment initiation. Because smooth crabgrass was controlled to such a high level by siduron, data are not shown.

At 28 DAE, an application timing by triclopyr rate interaction was observed for carpetweed control, and an application timing by fluazifop rate by triclopyr rate interaction was observed for goosegrass control and zoysiagrass injury. All herbicide treatments applied at seeding did not provide weed control or injure zoysiagrass. Pooled across fluazifop rates, 14 DAE treatments containing triclopyr controlled carpetweed 88% compared to 8% for those applied without triclopyr (data not shown). Goosegrass was controlled $\geq$ 72% for fluazifop alone (0.11 and 0.21 kg ha^{-1}) or tank-mixed with triclopyr (Table 1). Fluazifop alone at 0.11 and 0.21 kg ha^{-1} applied 14 DAE injured zoysiagrass 12 and 13%, respectively (Table 1). Zoysiagrass injury was reduced to 7% when fluazifop (0.11 and 0.21 kg ha^{-1}) was tank-mixed with triclopyr. Triclopyr applied alone controlled goosegrass 48% and caused no visible zoysiagrass injury. Patton et al. (2007) reported a broader range of Zenith zoysiagrass injury (8 to 50%) from fluazifop alone (0.07 kg ha^{-1}) over a 3-yr study, with environmental variability likely leading to the differences in zoysiagrass injury. The reduction of zoysiagrass injury from tank-mixtures of fluazifop plus triclopyr confirms results of Lewis et al. (2010) and McElroy and Breeden (2006), who reported applications of fluazifop tank-mixed with triclopyr (0.11 kg ha^{-1} plus 1.12 kg ha^{-1}) reduced injury to established stands of Cavalier, Meyer, Palisades, and Zenith zoysiagrass.

At 42 DAE, a fluazifop rate by triclopyr rate interaction was observed for goosegrass control and an application timing by fluazifop rate by triclopyr rate interaction was observed for zoysiagrass injury. Goosegrass control ranged from 67 to 78% from either rates of fluazifop alone or tank-mixed with triclopyr (Table 2). Regarding zoysiagrass injury, 28 DAE applications of fluazifop plus triclopyr were safe on zoysiagrass seedlings (Table 1). Fluazifop (0.11 and 0.21 kg ha^{-1}) applied alone 28 DAE injured zoysiagrass 12 and 16%, respectively, whereas the addition of triclopyr reduced injury to 6 and 9%, respectively. Zoysiagrass recovered from the 14 DAE applications ($\leq$ 5% injury). Triclopyr applied alone controlled goosegrass 43% and caused no visible zoysiagrass injury. As irrigation became less frequent and mowing height was reduced, carpetweed control was > 99% throughout the remainder of the study.

At 56 DAE, a fluazifop rate by triclopyr rate interaction was observed for goosegrass control and an application timing by fluazifop rate interaction was observed for zoysiagrass injury. Fluazifop alone or tank-mixed with triclopyr controlled goosegrass 70 to 75%; however, triclopyr alone controlled goosegrass 23% (Table 2). Zoysiagrass fully recovered from the 14 DAE application and injury was $\leq$ 6% for all treatments applied 28 DAE (Table 3). These results agree with those of Patton et al. (2007) who noted fluazifop injury persisted for a 21-d period before zoysiagrass seedling recovery.

At 98 DAE, the line intersect method was used to determine percent goosegrass and zoysiagrass cover. An application timing by fluazifop rate interaction was detected for goosegrass cover, and an application timing by fluazifop rate by triclopyr rate interaction was present for zoysiagrass cover. Goosegrass cover was $\leq$ 3% for treatments containing

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Table 2. Goosegrass control affected by fluazifop rate and triclopyr rate interaction 42 and 56 DAE.[a]

Herbicide[b]		Goosegrass control[c]	
Fluazifop	Triclopyr	42 DAE	56 DAE
—— kg ha^{-1},[d] ——		—— % ——	
0.11	0	73	75
0.21	0	78	74
0.11	1.12	71	70
0.21	1.12	67	71
0	1.12	43	23
$LSD_{(< 0.01)}$		12	11

[a] Abbreviation: DAE, days after emergence.

[b] A nonionic surfactant was included with each treatment at 0.25% v/v ratio.

[c] Evaluated visually on a 0 to 100% scale, based on a 0 = no control and 100 = complete plant death.

[d] Fluazifop displayed as kg ai ha^{-1}; triclopyr displayed as kg ae ha^{-1}.

Table 3. Zenith zoysiagrass injury 56 DAE and goosegrass cover 98 DAE affected by application timing and fluazifop rate interaction.[a]

Application timing (DAE)	Fluazifop rate[b]	Zoysiagrass 56 DAE	Goosegrass 98 DAE
	kg ai ha^{-1}	% Injury[c]	Cover[d]
Seeding	0	0	20
Seeding	0.11	0	17
Seeding	0.21	0	18
14	0	0	18
14	0.11	0	3
14	0.21	0	1
28	0	0	20
28	0.11	3	2
28	0.21	6	1
$LSD_{(< 0.01)}$		2	7

[a] Abbreviation: DAE, days after emergence.

[b] A nonionic surfactant was included with each treatment at 0.25% v/v ratio.

[c] Evaluated visually on a 0 to 100% scale, based on a 0 = no injury and 100 = complete plant death.

[d] Evaluated using the line intersect method on a 0 to 99 scale.

fluazifop applied 14 or 28 DAE (Table 3). All at seeding herbicide applications and 14 and 28 DAE application timings without fluazifop yielded the greatest goosegrass cover, ranging from 17 to 20%. Fluazifop tank-mixed with triclopyr contained greater zoysiagrass coverage than fluazifop applied alone 14 and 28 DAE (Table 2). At seeding, applications of fluazifop alone or tank-mixed with triclopyr yielded 65 to 75% zoysiagrass cover, which was similar coverage to triclopyr applied alone (72%) and the nontreated (74%). Fluazifop at 0.11 kg ha^{-1} applied 14 DAE alone or tank-mixed with triclopyr provided 83 and 87% cover, respectively. Fluazifop at 0.21 kg ha^{-1} plus triclopyr applied 14 DAE yielded 91% zoysiagrass cover, but the same timing and rate of fluazifop alone provided only 69% cover. Applications timings at 28 DAE of fluazifop (0.11 and 0.21 kg ha^{-1}) tank-mixed with triclopyr yielded 93 and 88% cover, respectively. However, similar fluazifop rates applied alone yielded only 76% cover. The reduction in zoysiagrass cover in the fluazifop applied alone vs. the triclopyr tank-mixture likely can be attributed to the phytotoxic effect of fluazifop applied alone soon after emergence when zoysiagrass seedlings are most susceptible to herbicide injury. These results confirm those of Patton et al. (2007), who reported fluazifop (0.07 kg ha^{-1}) should not be applied on zoysiagrass seedlings within 28 DAE. To the best of our knowledge, this is the first report of safening of fluazifop by the addition of triclopyr on zoysiagrass seedlings.

Research Implications. Zenith zoysiagrass is a viable alternative to traditional vegetative zoysiagrass establishment. However, it is critical to control summer annual weeds during establishment to optimize zoysiagrass cover (Carroll et al. 1996; Johnson; 1976; Patton et al. 2004b). These data indicate single PRE siduron application (6.7 kg ha^{-1}) and POST applications of fluazifop alone or tank-mixed with triclopyr applied 14 or 28 DAE can provide season-long smooth crabgrass and goosegrass control. The addition of triclopyr is necessary to safen fluazifop applications on seedling zoysiagrass and can provide effective control of many other broadleaf weeds that can infest newly seeded areas (Anonymous 2008). Tank-mixtures of fluazifop and triclopyr have been used to effectively control bermudagrass (*Cynodon* spp.) in mature zoysiagrass (Doroh et al. 2011; Lewis et al. 2010; McElroy and Breeden 2006). Based on results from this study, it could be possible to control bermudagrass during seeded zoysiagrass establishment with the use of fluazifop tank-mixed with triclopyr. These applications could greatly aid turfgrass managers wishing to transition their existing bermudagrass turf into zoysiagrass. Other AOPP herbicides have been safened for use on zoysiagrass with the addition of triclopyr, indicating more AOPP herbicides plus triclopyr could have utility in establishing seeded Zenith zoysiagrass (Doroh et al. 2011; Lewis et al. 2010; McElroy and Breeden 2006). Conversely, differences in AOPP herbicide tolerance have been reported among zoysiagrass cultivars (Lewis et al. 2010). Therefore, turfgrass managers should take caution when applying these treatments to other seeded zoysiagrass cultivars.

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