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Influence of Postemergence Herbicides on Tropical Soda Apple (*Solanum viarum*) and Bahiagrass (*Paspalum notatum*)[1]

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Abstract: Greenhouse and field experiments were conducted to evaluate herbicidal efficacy on tropical soda apple and bahiagrass. Acifluorfen, clopyralid, dicamba, fluroxypyr, picloram, and triclopyr were the most effective postemergence herbicides, providing > 90% control of tropical soda apple plants with no injury to bahiagrass 145 days after treatment (DAT). Glyphosate and imazapyr resulted in effective (> 90%) control of both seedling and mature tropical soda apple plants. However, these herbicides caused severe (> 90%) damage to bahiagrass. Control of tropical soda apple with 2,4-D, AC-263,222, diuron, fomesafen, lactofen, MSMA, sulfometuron, and triasulfuron was unacceptable (< 90%).

Nomenclature: 2,4-D, (2,4-dichlorophenoxy)acetic acid; AC-263,222, (±)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-5-methyl-3-pyridinecarboxylic acid; acifluorfen, 5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoic acid; clopyralid, 3,6-dichloro-2-pyridinecarboxylic acid; dicamba, 3,6-dichloro-2-methoxybenzoic acid; fluroxypyr, [(4-amino-3,5-dichloro-6-fluoro-2-pyridinyl)oxy]acetic acid; diuron, *N'*-(3,4-dichlorophenyl)-*N,N*-dimethylurea; fomesafen, 5-[2-chloro-4-(trifluoromethyl)phenoxy]-*N*-(methylsulfonyl)-2-nitrobenzamide; glyphosate, *N*-(phosphonomethyl)glycine; imazapyr, (±)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1*H*-imidazol-2-yl]-3-pyridine carboxylic acid; lactofen, (±)-2-ethoxy-1-methyl-2-oxoethyl 5-[2-chloro-4-(trifluoromethyl)phenoxy]-2-nitrobenzoate; MSMA, monosodium salt of MAA; picloram, 4-amino-3,5,6-trichloro-2-pyridinecarboxylic acid; sulfometuron, 2-[[[[(4,6-dimethyl-2-pyrimidinyl)amino]carbonyl]amino]sulfonyl]benzoic acid; triclopyr, [(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid; bahiagrass, *Paspalum notatum* Fluegge #[3] PASNO; tropical soda apple, *Solanum viarum* Dunal SOLVI.

Additional index words: Broadleaf weed, perennial weed control, 2,4-D, AC-263,222, acifluorfen, clopyralid, dicamba, diuron, fluroxypyr, fomesafen, glyphosate, imazapyr, lactofen, MSMA, picloram, sulfometuron, triasulfuron, triclopyr.

Abbreviations: DAT, days after treatment; TSA, tropical soda apple; POST, postemergence.

INTRODUCTION

Tropical soda apple (TSA), a new exotic weed, is rapidly spreading throughout the southeastern United States (Bryson and Byrd 1994; Mullahey and Cornell 1994). A perennial broadleaf weed, TSA is native to Brazil and Argentina and has established itself in Mexico, Honduras, the West Indies, and India (Bryson and Byrd 1994; Mullahey et al. 1993a). TSA is grown commercially in India for solasodine, an alkaloid substance found in TSA fruits (Krishnan 1983, 1987; Patil and Laloraya 1981; Reedy and Krishnan 1991; Reedy et al. 1991). TSA was first found in Hendry County, FL, in 1987, but it was not until 1988 that it was identified as a potential pest (Mullahey et al. 1993b). TSA has infested all 67 counties in Florida, and has now spread to over 200,000 ha of agricultural land (Mullahey and Cornell 1994). A few plants can infest a hectare of pasture land within 6 mo (Akanda et al. 1996). Florida cattle ranchers estimated that TSA cost the cattle industry $11 million by 1993 (Mullahey et al. 1994). TSA has been observed primarily in improved pastures, ditchbanks, citrus groves, sugar cane (*Saccharum officinarum* L.) fields, oak (*Quercus* spp.) hammocks, woods, fallow fields, and roadsides (Mullahey et al. 1993a, 1993b). It is commonly associated with soils of the Spodosol order, which are typically poorly drained and fairly level (Mullahey et al., 1993a). TSA infestation has also been reported in Georgia, Al-

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[3] Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds*, Revised 1989. Available from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

abama, Mississippi, and South Carolina (Bryson and Byrd 1994).

TSA is a member of the Solanaceae family, belonging to section Acanthophora, and Subgenus Leptostemonum (Nee 1991). TSA stands from 1 to 2 m tall, and has light-colored prickles on leaves, stems, petioles, and calyxes. The plant produces flowers and fruits 60 and 90 d after emergence, respectively (Akanda et al. 1996; Patterson and McGowan 1996). Immature fruits have mottled pigmentation similar to a watermelon [*Citrullus lanatus* (Thunb.) Mansf.] rind. Mature fruits are yellow, smooth, globular, and 20 to 30 mm diam. Seeds are reddish-brown and somewhat flattened, with an average of 413 per fruit (Mullahey 1993b). The average seed production was estimated at 50,000/season/plant (Mullahey 1993b). Seeds were readily disseminated by cattle, wildlife, and water to new areas, primarily in grazing pastures. Seed germination is rapid after passage through digestive systems (Akanda et al. 1995). Dissemination of seeds through herbivores is a primary force in the rapid spread of TSA (Akanda et al. 1995, 1996; Delaney et al. 1993). Seed germination and emergence is enhanced at temperatures between 20 to 30 C (Akanda et al. 1996; Vincente 1972a, 1972b), soil pH 6 to 8, and moderate soil moisture (Akanda et al. 1996). Maximum seed germination occurred at a planting depth of 5.6 cm (Akanda et al. 1996).

TSA is also spread vegetatively from the root system (Bryson and Byrd 1994; Mullahey and Cornell 1994). Horsenettle (*Solanum carolinense* L.) and robust horsenettle (*Solanum dimidiatum* Raf.), which are related to TSA, have been shown to have very high regenerative capacity from root sections ranging in size from 1 to 6 cm. Horsenettle root sections placed as deep as 16 cm had 100% emergence (Wehtje et al. 1987).

TSA has become a serious problem in many perennial grass pastures in Florida, where it lowers forage quality and quantity (Mullahey et al. 1993a). TSA can also serve as an alternative host for plant viruses (McGovern et al. 1994). Control of TSA is difficult due to its vigorous regeneration capability. Repeated applications of herbicides are necessary to control TSA completely. Many herbicidal treatments have been found effective against this species (Mullahey et al. 1993a). However, they are injurious to the pasture grasses associated with TSA. Recommendations currently include broadcast treatments with triclopyr, in combination with spot treatments of dichlorprop [(±)-2-(2,4-dichlorophenoxy)propanoic acid] and 2,4-D, which provided > 90% control of TSA (Mullahey 1993a). Metsulfuron {2-[[[[(4-methoxy-6-methyl-1,3,5-triazin-2-yl)amino]carbonyl]amino]sulfonyl]benzoic acid} alone only partially controlled TSA, while glyphosate and hexazinone [3-cyclohexyl-6-(dimethylamino)-1-methyl-1,3,5-triazine-2,4(1*H*,3*H*)-dione] provided 96 and 93% control of TSA, but severely injured pasture grasses compared to triclopyr (Mullahey 1993a). In addition to triclopyr, alternative herbicides need to be identified to completely control this invasive and aggressive weed.

The objective of this research was to evaluate efficacy of selected postemergence herbicide treatments including triclopyr for control (> 90%) of TSA plants without injury (< 5%) to bahiagrass.

MATERIALS AND METHODS

Greenhouse Experiments. Studies to evaluate the efficacy of herbicides applied postemergence (POST) to TSA and bahiagrass were conducted at Immokalee, FL. TSA and bahiagrass seed were planted on May 16 and June 2, 1994, in Speedling[4] trays and transferred to 900-ml styrofoam cups when seedlings were 5 to 9 cm tall. The cups contained Immokalee fine sand (sandy, siliceous, hyperthermic, Arenic Haplaquod). Transplanted seedlings were placed in a greenhouse with approximate day/night temperatures of 32/24 C and relative humidity from 50 to 90% under natural photoperiod. TSA plants at the five- to six-leaf stage (15 cm high) and bahiagrass at the four- to five-leaf stage (16 cm high) were treated on a spray table with a two-nozzle boom. Herbicide solutions were mixed with a nonionic surfactant[5] (0.25% v/v) and applied at a diluent volume of 190 L/ha at 100 kPa. Immediately after treatment, treated plants were moved to a greenhouse and watered to maintain adequate moisture. A dilute nutrient solution[6] was provided to each plant weekly up to 145 DAT.

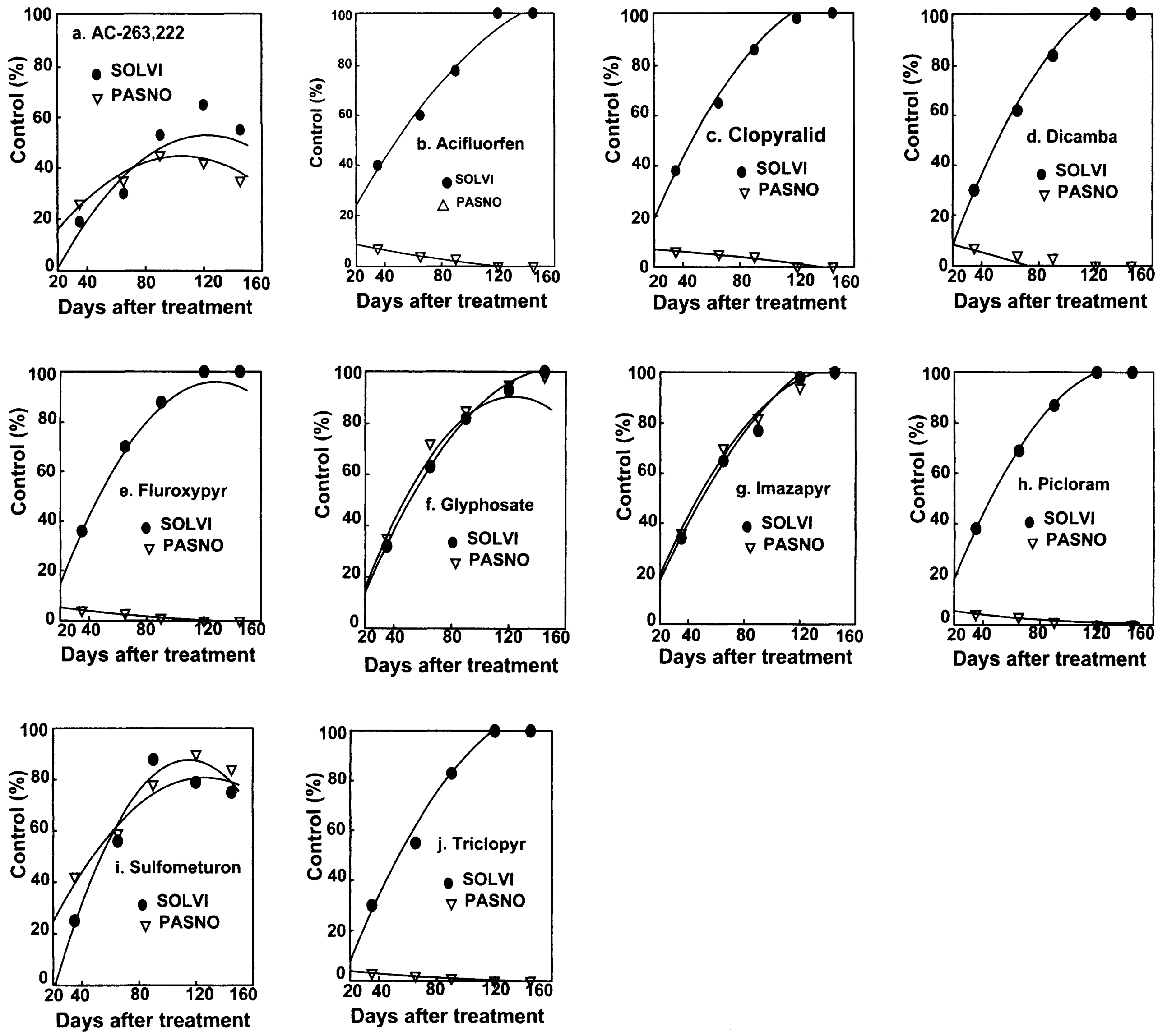
Injury was visually evaluated at 35, 65, 90, 120, and 145 DAT using a scale of 0 to 100, with 0 indicating no damage and 100 indicating plant death.

The experiment was established as a completely randomized design with four replications and was repeated. Data from each study were subjected to analysis of variance. There was no significant (P = 0.05) interaction between treatment and study; thus, data were pooled. Treatment means were separated using Fisher's Protected LSD test at P = 0.05 (SAS 1992).

[4] Speedling Inc., P.O. Box 7220, Sun City, FL 33586.

[5] Kinetic (polyalkyleneoxide modified polydimethyl siloxane and nonionic surfactants) from Setre Chemical Company, Memphis, TN 38137.

[6] Staren's Miracle-Grow Product, Inc., Consumer Product Division, P.O. Box 888, Port Washington, NY 11050.



Figures 1a–j. Response of SOLVI (tropical soda apple) and PASNO (bahiagrass) to selected POST herbicide treatments in field trials. AC-263,222 (0.1 kg/ha), SOLVI control (%) = $-21.5 + 1.22X - 0.005X^2$, $r^2 = 0.91$, PASNO control (%) = $0.63 + 0.84X - 0.004X^2$, $r^2 = 0.92$; acifluorfen (1.2 kg/ha), SOLVI control (%) = $2.7 + 1.12X - 0.003X^2$, $r^2 = 98$, PASNO control (%) = $11.04 - 0.13X + 0.0003X^2$, $r^2 = 0.97$; clopyralid (1.8 kg/ha), SOLVI control (%) = $-9.63 + 1.52X - 0.005X^2$, $r^2 = 0.99$, PASNO control (%) = $7.65 - 0.04X - 0.0002X^2$, $r^2 = 0.92$; dicamba (2.0 kg/ha), SOLVI control (%) = $-25.4 + 1.78X - 0.006X^2$, $r^2 = 0.99$, PASNO control (%) = $11.04 - 0.13X + 0.0003X^2$, $r^2 = 0.97$; fluroxypyr (1.0 kg/ha), SOLVI control (%) = $-18.4 + 1.79X - 0.007X^2$, $r^2 = 1.00$, PASNO control (%) = $6.9 - 0.09X + 0.0003X^2$, $r^2 = 0.96$; glyphosate (2.4 kg/ha), SOLVI control (%) = $14.57 + 1.52X - 0.005X^2$, $r^2 = 0.99$, PASNO control (%) = $-16.05 + 1.73X - 0.007X^2$, $r^2 = 0.99$; imazapyr (1.2 kg/ha), SOLVI control (%) = $-8.85 + 1.34X - 0.004X^2$, $r^2 = 0.99$, PASNO control (%) = $-8.14 + 1.48X - 0.005X^2$, $r^2 = 0.99$; picloram (1.5 kg/ha), SOLVI control (%) = $-12.85 + 1.66X - 0.006X^2$, $r^2 = 0.99$, PASNO control (%) = $6.9 - 0.09X + 0.0003X^2$, $r^2 = 0.96$; sulfometuron (0.5 kg/ha), SOLVI control (%) = $-44.37 + 2.3X - 0.01X^2$, $r^2 = 0.95$, PASNO control (%) = $1.47 + 1.26X - 0.005X^2$, $r^2 = 0.97$; triclopyr (2.4 kg/ha), SOLVI control (%) = $-22.88 + 1.63X - 0.005X^2$, $r^2 = 0.98$, PASNO control (%) = $4.978 - 0.06X + 0.0002X^2$, $r^2 = 0.98$. Note that these data are the averages of 1994 and 1995.

Field Experiment. Based on previous greenhouse experiments, studies were conducted in 1994 and 1995 in Hendry County, FL, with the selected herbicides (Figures 1 a–j). These herbicides effectively (> 90%) controlled TSA without bahiagrass injury (< 5%). The study site was an improved pasture with bahiagrass cover (100%) that had previously been grazed for 12 yr. The soil was an Oldsmar Sand (sandy, siliceous, hyperthermic Alfic Arenic Haplaquods) with 22% sand, 62% silt, 16% clay, 1% organic matter, and pH 6.9. TSA plants selected for this study had flowers and fruits (80 to 90 d old). Stand counts/plot, plant height, branch and tiller numbers/plant were determined prior to herbicide application (Table 1). Herbicide treatments were applied on November 28, 1994 and December 4, 1995, to 5.8- by 10-m plots arranged in a randomized complete block design with four replicates. Herbicides were applied at 190 L/ha with a CO_2 pressurized backpack sprayer at a pres-

Table 1. Initial tropical soda apple density, height, branches, and tiller numbers before herbicide treatments.

Herbicide treatment	Plant stand	Plant height	Branches	Tillers
	No./plot	cm	No./plant	No./plant
AC-263,222	33	62	9	3
Acifluorfen	37	65	8	4
Clopyralid	36	69	12	5
Dicamba	38	67	9	3
Fluroxypur	36	64	13	2
Glyphosate	34	67	9	4
Imazapur	35	66	8	3
Picloram	35	64	10	4
Sulfometuron	34	65	8	4
Triclopyr	37	63	11	4
Control	33	65	9	5
LSD (0.05)	6	11	7	5

sure of 137 kPa with a double-nozzle boom. A nonionic surfactant[7] (0.25% v/v) was added to all treatments. TSA control and bahiagrass injury were visually rated at 35, 65, 90, 120, and 145 DAT on a scale of 0 to 100% as described previously.

Data were subjected to analysis of variance to test for herbicide effects. Interactions were not present between year and treatment, so the data were combined for analysis. Treatment means were separated with Fisher's Protected LSD test at P = 0.05. Regression analysis was conducted on means to determine the effect of POST herbicide treatments on TSA and bahiagrass control.

[7] Latron AG-98 nonionic surfactant (90% alkylaryl polyoxethylene glycol and alcohol), Rohm and Haas Company, 100 Independence Mall West, Philadelphia, PA 19106.

RESULTS AND DISCUSSION

Greenhouse Experiments. Acifluorfen at 1.2 kg/ha, clopyralid at 1.8 kg/ha, dicamba at 2.0 kg/ha, fluroxypyr at 1.0 kg/ha, MSMA at 4.0 kg/ha, and picloram at 1.5 kg/ha were the only treatments that resulted in > 30% control of TSA plants and < 5% injury of bahiagrass compared to triclopyr at 2.4 kg/ha, which provided 32% control of TSA plants with 2% injury of bahiagrass 35 DAT (Table 2). AC-263,222 at 0.1 kg/ha, diuron at 3.5 kg/ha, glyphosate at 2.4 kg/ha, imazapyr at 1.2 kg/ha, lactofen at 1.2 kg/ha, sulfometuron at 0.5 kg/ha, and triasulfuron at 0.3 kg/ha also provided > 30% TSA control; however, these herbicides injured bahiagrass > 25% at 35 DAT. Acifluorfen, clopyralid, dicamba, fluroxypyr, picloram, and triclopyr showed excellent control (> 90%) of TSA without injuring bahiagrass 65 and 145 DAT. AC-263,222, glyphosate, imazapyr, and sulfometuron gave > 90% control of TSA and bahiagrass at 145 DAT.

TSA is primarily found in pastures and oak hammocks in Florida (Akanda et al. 1996). A hammock is a shaded area of perennial oak trees and is a part of pasture. Acifluorfen, clopyralid, dicamba, fluroxypyr, or picloram could be applied to control TSA plants in pastures, and AC-263,222, glyphosate, imazapyr, and sulfometuron could be applied in hammock areas where nontarget species injury is not a high priority. Herbicide treatments that resulted in > 90% TSA control at 145 DAT were selected for field evaluation using similar rates. It should be noted that imazapyr application may

Table 2. Response of tropical soda apple (SOLVI) and bahiagrass (PASNO) to selected POST herbicide treatments in the greenhouse at Immokalee, FL.

		Injury[a]									
		35 DAT		65 DAT		90 DAT		120 DAT		145 DAT	
Herbicide	Rate	SOLVI	PASNO	SOLVI	PASNO	SOLVI	PASNO	SOLVI	PASNO	SOLVI	PASNO
	kg ai/ha	%									
2,4-D	2.5	18	2	76	0	60	0	57	0	38	0
AC-263,222	0.1	38	26	91	68	100	85	100	91	100	91
Acifluorfen	1.2	33	2	95	0	100	0	100	0	100	0
Clopyralid	1.8	35	3	92	0	99	0	100	0	100	0
Dicamba	2.0	34	1	91	0	100	0	100	0	100	0
Diuron	3.5	36	28	60	45	85	36	82	31	79	29
Fluroxypyr	1.0	40	1	99	0	100	0	100	0	100	0
Fomesafen	1.0	27	9	46	25	85	26	90	32	88	39
Glyphosate	2.4	37	31	91	93	92	93	96	95	100	100
Imazapyr	1.2	39	31	92	91	96	93	100	100	100	100
Lactofen	1.2	38	26	85	39	85	40	80	36	74	33
MSMA	4.0	36	0	87	4	83	6	80	6	65	5
Picloram	1.5	42	1	96	0	99	0	100	0	100	0
Sulfometuron	0.5	37	40	92	98	100	98	100	100	100	100
Triasulfuron	0.3	40	30	49	24	45	55	40	61	38	66
Triclopyr	2.4	32	2	99	0	100	0	100	0	100	0
Control	0	0	0	0	0	0	0	0	0	0	0
LSD	0	9	7	12	13	5	10	5	10	4	10

[a] Rated on a 0 to 100 scale. 0 = no injury, 100 = death of plants.

result in severe injury to oak in hammocks (Ahrens 1994). Imazapyr usually stays within the top 50 cm of soil, and may not affect mature oaks. However, injury to immature oaks can be reduced by lowering herbicide rates.

Field Study. Compared to triclopyr, acifluorfen, clopyralid, dicamba, fluroxypyr, and picloram at 1.2, 1.8, 2.0, 1.0, and 1.5 kg/ha, respectively, provided excellent control (100%) of TSA without damaging bahiagrass 120 and 145 DAT (Figures 1 b–e, 1j). These herbicides controlled TSA > 60% 65 DAT and > 80% 90 DAT with < 5% bahiagrass injury. According to greenhouse studies, acifluorfen, clopyralid, dicamba, fluroxypyr, and picloram provided 90 and 100% control of TSA 65 DAT and 90 DAT, respectively, with < 3% injury to bahiagrass. Increased control of greenhouse-grown plants may have been due to younger plants (45 d) compared to older plants in the field (80 to 90 d). Studies found that clopyralid, dicamba, picloram, and triclopyr effectively translocated into the roots and exhibited excellent long-term control of horsenettle when applied annually for at least 2 yr (Gorrell et al. 1981, 1988; Holloway and Cole 1993). AC-263,222 (0.1 kg/ha) and sulfometuron (0.5 kg/ha) controlled TSA 65% 120 DAT and 88% 90 DAT, but plants recovered by 145 DAT (Figures 1a and 1i). These results are inconsistent with greenhouse studies described previously where both herbicides provided 100% control of TSA 145 DAT. Greenhouse- and field-grown plant size (15 vs. 66 cm) and age (45 vs. 85 d) are probable reasons for differences in results. Glyphosate (2.4 kg/ha) and imazapyr (1.2 kg/ha) controlled > 90% of TSA and bahiagrass 120 and 145 DAT (Figures 1f and 1g). Control of TSA > 90% at 120 DAT is an indication that the plants are dead and their root systems are also killed. Final evaluation made for long-term control of TSA indicated that plants controlled > 90% at 120 DAT were completely dead (100%) at 145 DAT. No regrowth from perennial root systems was found, and both underground and aboveground parts of the TSA plants were killed.

Control of TSA before flowering with herbicide treatments is desirable primarily to stop seed production. Because TSA seeds are viable for more than a year, an effective long-term management strategy is required (Mullahey and Cornell 1994). Long-term control is especially important for a species such as TSA that causes problems in pasture and rangeland systems where continuous chemical input is not economically feasible. Acifluorfen, clopyralid, dicamba, fluroxypyr, picloram, and triclopyr could be applied for the early control of TSA in pastures. Early control of TSA in pastures is beneficial with respect to forage production, forage cover, and competition of forages with TSA. Glyphosate and imazapyr would not be recommended to control TSA in pastures because of high injury to bahiagrass. Hammock areas, roadsides, ditchbanks, and other fallow areas serve as major TSA seedbanks where wildlife congregate and deposit seeds via defecation, resulting in new TSA infestations. These areas should be spot treated with glyphosate or imazapyr to control TSA. These herbicides have limited activity on hardwoods.

Compared to triclopyr, acifluorfen, clopyralid, dicamba, fluroxypyr, and picloram provided the best control of TSA with the least injury to bahiagrass. These herbicides injured bahiagrass initially; however, the injury was transient. Initial bahiagrass injury was reduced by lowering rates. Glyphosate and imazapyr damaged bahiagrass, creating open, bare patches of soil for TSA seedlings to emerge. Thicker grass groundcover may help reduce emergence of new TSA seedlings and increase the amount of forage available to cattle. Glyphosate and imazapyr would not be suitable to control TSA in pastures because of severe injury to bahiagrass. Acifluorfen, clopyralid, dicamba, fluroxypyr, picloram, and triclopyr could be applied POST to control TSA in pastures, and glyphosate or imazapyr could be applied as spot treatments to control TSA in hammocks, roadsides, ditchbanks, and other areas where nontarget species injury is not a high priority.

Because TSA causes problems in relatively "low-input" agroecosystems, low-cost long-term solutions are essential. Thus, killing one generation of TSA is not sufficient; repeated herbicide applications are essential for the long-term management of this species.

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