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Research Article

Efficacy of Postemergence Herbicides for Control of Small-Leaf Spiderwort (*Tradescantia fluminensis*) in Florida

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ABSTRACT

Tradescantia fluminensis (small-leaf spiderwort; SLSW) is a fast-growing herbaceous groundcover and one of the most problematic invasive plants in Florida. The objective of this research was to determine the efficacy of selected postemergence herbicides for SLSW control in greenhouse and field experiments in Florida. An additional objective was to determine if pre-cutting plants would increase herbicidal efficacy. In greenhouse experiments, cutting mature SLSW plants increased the control of most herbicides evaluated. Overall, triclopyr ester provided the highest level of control along with triclopyr amine, triclopyr choline, and glufosinate, all of which were similar. Few differences were observed between 2,4-D, aminopyralid, metsulfuron-methyl, sulfentrazone, and glyphosate and all provided ≤66% control as evidenced by shoot weight reduction. In field experiments, pre-cutting SLSW had no effect on herbicide efficacy. Triclopyr was again generally the most efficacious treatment, outperforming glyphosate, aminopyralid, glufosinate, and fluroxypyr on most evaluation dates, especially as trials progressed past 5 mo. Overall, data suggest that triclopyr would be the most effective option for SLSW management. However, as efficacy was noted with fluroxypyr, glyphosate, and glufosinate depending upon location, other options exist. Further research is needed to determine reapplication intervals and effects on nontarget native plants in order to develop comprehensive management plans.

Index terms: herbicide; invasive plant; postemergence; small-leaf spiderwort; *Tradescantia fluminensis*

INTRODUCTION

Tradescantia fluminensis Vell. (small-leaf spiderwort; SLSW) is a fast-growing herbaceous groundcover that roots extensively along its nodes and forms dense vegetative mats that displace native forest understory plants (Esler 1962; Standish 2002). Native to Brazil, SLSW was introduced into Florida as an ornamental groundcover but soon escaped cultivation. This invasive plant is currently listed as a Category I exotic plant pest and has been documented in over 30 counties in Florida (FLEPPC 2019; EDDMapS 2021). SLSW has been rated as one of the most threatening environmental weeds in several countries, most notably New Zealand (Hurrell et al. 2009) due to its ability to outcompete native vegetation and other negative impacts it causes on native wildlife, insects, and soil microorganisms (Yeates and Williams 2001). This species alters litter decomposition, nutrient cycling, and invertebrate biodiversity, and disrupts the natural succession of native plant species from season to season, leading to low diversity in understory plant habitats (Kelly and Skipworth 1984a; Standish 2001; Standish et al. 2001). Impacts of SLSW are especially severe in areas where the forest canopy has been opened as growth increases exponentially when exposed to high levels of sunlight (Kelly and Skipworth 1984a). Once SLSW has heavily infested an area, it is unlikely that the forest will be able to regenerate itself without intervention. Dense mats up to 60 cm thick may eventually form, inhibiting germination of other plant species. Kelly and Skipworth (1984a) estimated that 1 m^2 of ground could contain up to 300 SLSW plants with a total stem length of 900 m.

SLSW is difficult to manage despite the fact that reproduction is reported to be exclusively or at least predominantly vegetative via stem fragment dispersal (Healy and Edgar 1980). Kelly and Skipworth (1984a) reported that fragments as small as 10 mm can become established plants if there is a single node on the fragment, and estimated growth rates at 0.2–0.3 cm per day.

The physiology of SLSW allows it to respond rapidly to two main resources, light and nitrogen. Maule et al. (1995) reported that irradiance level is likely the primary factor determining SLSW populations and that population density increased with increasing light levels, such as those found near the edges of forest remnants. Furthermore, Esler (1962, 1988) reported that SLSW invasion in forests was particularly severe following a disturbance (i.e., treefall) that caused canopy degeneration. While increased growth has been observed in high light environments, SLSW is adapted to shaded areas but may need high soil moisture levels in order to thrive in these environments (Maule et al. 1995).

Although SLSW is an invasive plant of increasing economic importance, little research has focused on identifying effective management practices. Previous research has predominantly focused on chemical control evaluating triclopyr or glyphosate at varying rates. Hurrell et al. (2009) evaluated triclopyr (no formulation given) at rates ranging from 1.2 to 14.4 kg ha^{-1}. SLSW control generally increased with increasing triclopyr rate and rates as low as 3.6 kg ha^{-1} reduced biomass by over 99% 448 d after treatment. McCluggage (1998) evaluated triclopyr ester, metsulfuron-methyl, glyphosate, and amitrole. Although no statistical analysis was performed, the authors reported triclopyr

Table 1.—Postemergence herbicides evaluated in greenhouse or field experiments for control of small-leaf spiderwort in Florida. Application rates are shown in kg active ingredient (ai) or acid equivalent (ae) applied per ha. The highest label rates of aminopyralid, glufosinate, glyphosate, and triclopyr ester were evaluated in field trials. Fluroxypyr was only evaluated in field trials.

Herbicide	Trade name	Rates (kg ha^{-1})	Manufacturer, city, state
2,4-D	2,4-D amine	1.2 and 2.2 ae	Southern Agricultural Insecticides, Inc., Rubonia, FL
Aminopyralid	Milestone	0.03, 0.06, 0.12 ai	Corteva Agriscience, Indianapolis, IN
Fluroxypyr	Vista XRT	0.28 ai	Corteva Agriscience, Indianapolis, IN
Glufosinate	Finale	0.84 and 1.7 ai	BASF Corp., Research Triangle Park, NC
Glyphosate	Ranger Pro	1.7 and 3.4 ai	Monsanto Co., St. Louis, MO
Metsulfuron-methyl	Escort XP	0.02 and 0.04 ai	Bayer Environmental Science, Research Triangle Park, NC
Sulfentrazone	Dismiss	0.21 and 0.42 ai	FMC Corporation, Philadelphia, PA
Triclopyr amine	Garlon 3A	1.7 and 3.4 ae	Corteva Agriscience, Indianapolis, IN
Triclopyr ester	Garlon 4	1.7 and 3.4 ae	Corteva Agriscience, Indianapolis, IN
Triclopyr choline	Vastlan	1.7 and 3.4 ae	Corteva Agriscience, Indianapolis, IN

was the most efficacious treatment and required fewer sequential applications than other herbicides. Glyphosate was once one of the primary control options for SLSW treatment in Florida, but results have been inconsistent. McCluggage (1998) reported over 95% control after two applications with a 3% glyphosate solution. In contrast, Kelly and Skipworth (1984a) reported SLSW treated with glyphosate were similar to nontreated plants in biomass and number of live nodes. Kelly and Skipworth (1984b) evaluated other herbicides including paraquat and asulam, but little to no long-term control was observed.

Non-chemical management methods have also been evaluated with a goal of preventing nontarget damage to native vegetation. Artificial shading (reducing ambient light by 80–90%) has been shown to reduce SLSW cover by over 60% and was less injurious to native tree seedlings compared with use of herbicides, but this approach would likely not be feasible in large-scale infestations (Standish 2002). Hand weeding and manual removal have also been examined with mixed results. In most cases, hand weeding significantly reduces SLSW cover for several months following removal, but cover soon increases to previous levels if the process is not repeated, rendering this method ineffective and economically unfeasible for large areas (Ogle and Lovelock 1989; Standish 2001).

Previous research has predominantly focused on use of herbicides or non-chemical management techniques for SLSW, but these treatments and management approaches have not been evaluated in combination. Further, the only herbicidal active ingredients that have been adequately evaluated for efficacy are glyphosate and triclopyr, and in many cases, these herbicides are applied as a v:v concentration (e.g., 3%) with no mention of application volume or active ingredient applied per unit area. The objective of this research was to identify effective herbicide options for SLSW. Due to the dense mat-forming growth nature, pre-cutting SLSW prior to herbicide treatment was also evaluated in combination with herbicide treatment to determine if efficacy could be increased in greenhouse and field experiments.

METHODS

Greenhouse experiments were conducted at the Mid-Florida Research and Education Center in Apopka, Florida (28.2382°N, 81.5486°W) from 2017 to 2018. SLSW cuttings were collected from populations growing in a city park in Gainesville, Florida (29.6208°N, 82.3335°W) (2017) and from a state park in Bristol, Florida (30.5747°N, 84.9608°W) (2018). Cuttings were kept in open plastic bags until arrival at the Mid-Florida Research and Education Center and then transferred to coolers until sticking cuttings the following day. Four terminal cuttings (6.5 cm) containing 3–4 leaves were stuck into 1 L nursery containers that had been previously filled with a pinebark:peat horticultural substrate amended with peat, perlite, vermiculite, and dolomitic limestone (Fafard 52 growing mix; SunGro Horticulture, Agawam, Massachusetts). Fertilizer (Osmocote Plus 15-9-12; ICL Specialty Fertilizers, Dublin, Ohio) was incorporated into the substrate at a rate of 3 kg m^{-3} prior to sticking cuttings. After sticking, pots were placed in a shaded greenhouse (60% of ambient sunlight) and received 0.6 cm of overhead irrigation per day. Plants were allowed to grow for approximately 8 wk, at which time plant roots were inspected visually to ensure at least 80% of the root ball contained visible roots. Plants were then sorted into two separate groups. The first group was left growing as is and the second group was cut with pruners 2.5 cm above the soil line (pre-cutting treatment). Plants were then allowed to grow for an additional 7 d. At this time, pots were removed from the greenhouse and herbicides (Table 1) were applied using a CO_2 backpack sprayer calibrated to deliver 233 L ha^{-1} using a TeeJet 8004 flat fan nozzle (TeeJet Technologies, Glendale Heights, Illinois) at 241 kPa. Plants were then moved back inside the greenhouse mentioned above for the remainder of the experiment and received overhead irrigation each day (0.6 cm). A group of non-treated controls were maintained for each non-chemical treatment (pre-cutting or no cutting/as is). Herbicide treatments were applied in February 2017 using 12 single pot replicates per treatment. The trial was repeated using the same methodology in June 2017 and in July 2018 with the only exception being that 8 and 4 single pot replications were included in the June 2017 and July 2018 trials, respectively. In each of the three experimental replications, herbicide treatments were only applied one time. All trials utilized a completely randomized design with factorial treatment structure of nine herbicides, two rates of each herbicide, and two pre-application treatments (pre-cutting or none).

Following initiation of greenhouse experiments and preliminary results, field experiments were initiated at two locations in Florida in the winter season of 2017–2018. Locations chosen for

Table 2.—Results of mixed model analysis of variance showing main effects of herbicide, rate, pre-treatment cutting, and all interactions on small-leaf spiderwort control in greenhouse experiments. Results are pooled over three experimental runs.

Main effects	*P*
Herbicide (H)	<0.0001
Rate (R)	<0.0001
Pre-treatment cutting (C)	<0.0001
Interactions	
H × R	<0.0001
H × C	0.0032
R × C	0.0289
H × R × C	0.5235

experiments included Torreya State Park (TSP) in Bristol, Florida (30.5747°N, 84.9608°W) and Payne's Prairie Preserve (PPP) in Gainesville, Florida (29.6102°N, 82.3014°W) with dense and uniform SLSW populations. The TSP site was a dry flood plain heavily infested with SLSW with dense mats approximately 25–30 cm thick in the forest understory. The PPP site was also heavily infested, but mats were only approximately 12 cm thick. Each site was subdivided into 20 separate treatment plots, approximately 12 m^2, with flags and wooden stakes. On the day of herbicide treatment, half of each experimental plot (6 m^2) was cut back to approximately 7.5 cm in height using a gas powered string trimmer with a goal of increasing herbicide penetration through the dense mat-like growth. The other half of each plot (6 m^2) was left as is. Following plot establishment and pre-treatment cutting, herbicides including aminopyralid [0.12 kg active ingredient (ai) ha^{-1}], fluroxypyr (0.28 kg ai ha^{-1}), glufosinate (1.68 kg ai ha^{-1}), glyphosate (3.4 kg ai ha^{-1}), and triclopyr ester [3.4 kg acid equivalent (ae) ha^{-1}] were applied on 20 December 2017 at TSP and 15 January 2018 at PPP using the same methods described previously. While plants were allowed to regrow prior to treatment in initial greenhouse trials, cutting and herbicide application were conducted on the same day in the field for two reasons. First, managers had communicated that it may be difficult to make frequent visits to remote treatment sites and requested data on cutting on the day of herbicide application. Secondly, there were resource limitations that limited the number of treatment factors and site visits that could be included in field trials. Glufosinate and triclopyr were included due to high efficacy observed in greenhouse trials while aminopyralid and glyphosate were included due to their selectivity (aminopyralid) or absence of soil residual effects (glyphosate). Fluroxypyr was not previously evaluated in greenhouse experiments, but was included in field experiments based on previous efficacy on *Commelinaceae* species and poor efficacy observed with most other herbicides evaluated in greenhouse experiments (Isaac et al. 2013). The trial was designed as a factorial complete randomized block design with five herbicide treatments and two pre-application treatments (pre-cutting or none) with four single replications per treatment at each location. Following treatment, visual control ratings were recorded on a 0 to 100 scale where 0 = no control, similar in appearance to non-treated control plots, and 100 = total control and no living SLSW tissues visible. Ratings were taken at TSP at 1, 3, 4, and 5 mo after treatment (MAT) and at 1, 3, 4, 5, and 6 MAT at PPP. In 2018, the trial was repeated at another nearby location in PPP with herbicides being applied in the same manner on 24 September 2018. As pre-cutting was found to be ineffective during the first experimental runs at both locations, no pre-application cutting occurred prior to herbicide treatment in the second experimental run at PPP. In the second experimental run at PPP, visual ratings were recorded monthly for 8 MAT.

Data Analysis

Percent control data (based on shoot dry weight reduction in comparison with nontreated plants) in greenhouse trials were subjected to a mixed model ANOVA using SAS Proc Mixed (SAS Institute, Cary, North Carolina) reflecting the factorial treatment arrangement. Replication (block) was considered a random effect while trial run (or year), herbicide, rate, pre-treatment cutting, and interactions between these terms were treated as fixed factors. Percent control of each herbicide treatment relative to the nontreated control was calculated for each replication prior to analysis, therefore data from the nontreated control group were not analyzed. Means were separated using Fisher's least significance difference Test ($P \leq 0.05$) when effects (herbicide, rate, pre-cutting, or interactions) were found to be significant. Model assumptions of constant variance and normality were checked and percentage data were arcsine square root transformed as needed to meet the assumptions of normality prior to analysis (Ahrens et al. 1990). Back-transformed means are presented for clarity. Results from all experimental runs were pooled for analysis because there were no year by treatment interactions. Data collected in the field were analyzed in the same manner. Due to significant location by treatment interactions, data from TSP and PPP were analyzed separately although data from PPP were pooled over both experimental runs in (2017 to 2018 and 2018 to 2019) due to no experimental run by treatment interaction.

RESULTS

Greenhouse experiments

Main effects of herbicide, rate, and pre-treatment cutting were significant but were confounded by interactions between herbicide and rate, herbicide and pre-treatment cutting, and rate and pre-treatment cutting, which were also significant (Table 2). Averaged over all herbicides, a higher control was achieved with the high rate compared to when low rates were applied when SLSW were cut prior to treatment (Figure 1). When no pre-application cutting was performed, an overall lower level of control was observed, and there was no significant difference in herbicide rate.

Pooled over both pre-application cutting treatments, greater SLSW control was observed with the high rate of aminopyralid (52% vs. 43%), glufosinate (83% vs. 67%), glyphosate (51% vs. 36%), and metsulfuron (48% vs. 29%) (Figure 2). There was no significant difference observed in the rates of 2,4-D or sulfentrazone in which neither herbicide provided greater than 72% control regardless of cutting treatment. Similarly, there was no significant difference in SLSW control based on rate of any

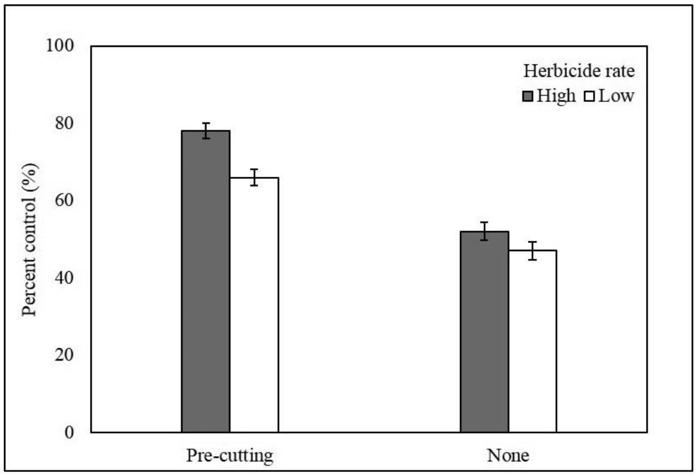

Figure 1.—Interaction of pre-cutting vs. not pre-cutting small-leaf spiderwort (SLSW) prior to herbicide application on SLSW control as determined by percent reduction in shoot dry weight in relation to non-treated control plants in greenhouse experiments. Herbicides tested included 2,4-D, aminopyralid, glufosinate, glyphosate, metsulfuron-methyl, sulfentrazone, and amine, ester, and choline formulations of triclopyr applied at low and high label rates. Means and standard errors are shown for each rate within each cutting treatment pooled over all herbicides.

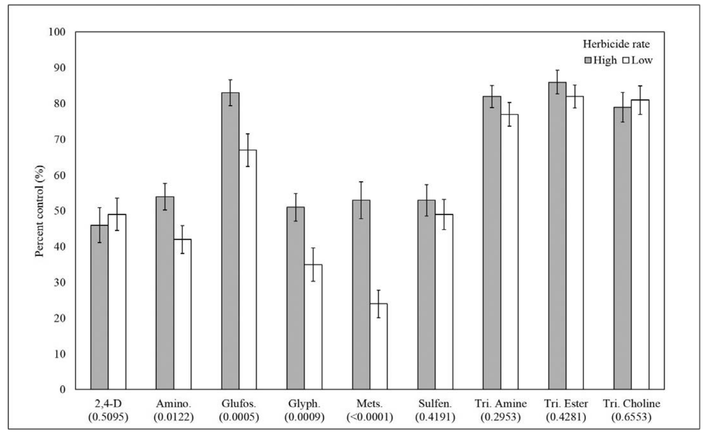

Figure 2.—Interaction effects of herbicide and rate on small-leaf spiderwort (SLSW) control as determined by percent reduction in shoot dry weight in relation to non-treated control plants in greenhouse experiments. Herbicides evaluated included 2,4-D (2,4-D), aminopyralid (Amino.), glufosinate (Glufos.), glyphosate (Glyph.), metsulfuron-methyl (Mets.), sulfentrazone (Sulfen.), and amine (Tri. Amine), ester (Tri. Ester), and choline (Tri. Choline) formulations of triclopyr applied at low and high label rates. Means and standard errors are shown for each herbicide applied at a low and high label rate pooled over both pre-cut SLSW and SLSW that were not pre-cut prior to herbicide treatment. *P* values comparing rates within each herbicide are shown parenthetically below each herbicide abbreviation.

triclopyr formulation with all formulations and rates providing over 80% control across both pre-application cutting treatments.

When averaged over both high and low application rates, the highest level of control was observed with triclopyr ester (73%) and the other two triclopyr formulations, which provided statistically similar control (67% and 65% control with amine and choline formulations, respectively) when no pre-application cutting was performed (Table 3). The next highest level of control was observed in SLSW treated with glufosinate (61% control), which provided control similar to what was observed with triclopyr amine and choline. Few differences were noted among plants treated with 2,4-D, aminopyralid, glyphosate, metsulfuron-methyl, or sulfentrazone with all providing $\leq$43% control. Overall, a higher level of control was observed with all herbicides when SLSW was cut prior to treatment. In SLSW that were pre-cut, the highest control was observed with glufosinate (89%), and all three triclopyr formulations (93%, 96%, and 95% with amine, ester, and choline, respectively). Sulfentrazone provided the next highest level of control (66%) and while control was less than what was observed with triclopyr or glufosinate, sulfentrazone provided greater control than 2,4-D (54%), aminopyralid (53%), glyphosate (52%), and metsulfuron-methyl (51%).

As previously mentioned, a high level of control was observed with glufosinate and all three triclopyr formulations in greenhouse trials, therefore these herbicides were chosen for further evaluation in the field. As no differences were observed in triclopyr formulation, the ester formulation was selected for field evaluations because it is a lower risk formulation in regard to applicator safety, and at the time of these experiments, was more widely available than the recently released choline formulation. Few differences were observed between 2,4-D, aminopyralid, glyphosate, metsulfuron-methyl, or sulfentrazone in greenhouse experiments. However, while few differences were noted in terms of efficacy, glyphosate was chosen because it has no soil residual effects, which would be important for restoration purposes, and has been reported to be effective for SLSW management previously (McCluggage 1998). Similarly, aminopyralid was selected for field evaluation due to its broadleaf selectivity but was evaluated at 0.12 kg ai ha^{-1} in field, equivalent to the maximum label rate and twice the highest rate evaluated in greenhouse experiments. Fluroxypyr was also included based on cooperator interest and previously reported efficacy on similar species in the same family (Isaac et al. 2013).

Field Experiments

Although pre-cutting was performed at both PPP and TSP during the first year of evaluations, by 1 MAT there was no discernible visual difference in pre-cutting vs. no pre-cutting in any herbicide treated plot, and efficacy ratings were consistent over entire treatment plot regardless of pre-treatment cutting. In non-treated controls, there was no visual difference in SLSW height or coverage in plots that had been pre-cut compared with the portion of the plot left as is. Because there was no variation in ratings among the pre-cut and as is treatments, pre-cutting was not included as a variable in the analysis.

Data revealed significant site by treatment interactions but no year by site interactions for PPP, therefore separate ANOVAs were performed for each site but data for both years was combined at PPP. At PPP, fluroxypyr and triclopyr (both 100% control) provided greater control of SLSW than any other herbicide at 1 MAT (Table 4). The second most efficacious treatments included glufosinate (90%) and glyphosate (94%) followed by aminopyralid, which provided the lowest level of

Table 3.—Small-leaf spiderwort response to selected herbicides and pre-treatment cutting or no cutting in greenhouse experiments. Results are pooled over three experimental runs. Herbicide rates are presented in kg active ingredient (ai) or acid equivalent (ae) per hectare. Percent control (and standard error) are based on shoot dry weight reduction in comparison with non-treated control groups for pre-cutting or no pre-cutting. Means were pooled over both rates for each herbicide due to significant herbicide × pre-cutting interactions. Means within columns followed by the same letter are not significantly different according to Fisher's protected LSD ($P = 0.05$).

Herbicide	Rate (kg ha^{-1})	Pre-treatment			
		None	Mean	Pre-cutting	Mean
		% control			
2,4-D	1.1 ae	41 (7)	41 (5) cd	57 (7)	54 (4) c
	2.2 ae	40 (7)		51 (6)	
Aminopyralid	0.03 ai	41 (4)	43 (4) c	44 (6)	53 (4) c
	0.06 ai	46 (5)		62 (6)	
Glufosinate	0.84 ai	53 (6)	61 (4) b	81 (2)	89 (3) a
	1.7 ai	69 (6)		97 (5)	
Glyphosate	1.7 ai	31 (4)	33 (4) de	40 (5)	52 (5) c
	3.4 ai	36 (6)		65 (7)	
Metsulfuron-methyl	0.02 ai	25 (5)	26 (4) e	33 (8)	51 (6) c
	0.04 ai	28 (3)		68 (7)	
Sulfentrazone	0.21 ai	38 (5)	36 (4) cd	61 (5)	66 (4) b
	0.42 ai	34 (5)		72 (6)	
Triclopyr amine	1.7 ae	63 (5)	67 (3) ab	91 (2)	93 (2) a
	3.4 ae	70 (5)		94 (3)	
Triclopyr ester	1.7 ae	73 (6)	73 (4) a	92 (1)	96 (2) a
	3.4 ae	74 (5)		99 (3)	
Triclopyr choline	1.7 ae	67 (6)	65 (4) ab	96 (2)	95 (1) a
	3.4 ae	63 (6)		94 (1)	

control (79%). By 2 MAT, some recovery was observed in all treatments but was minimal. At this time, triclopyr (98% control) provided a significantly higher level of control compared with all other herbicides. By 3 MAT, triclopyr was again the most efficacious treatment (98% control) followed by fluroxypyr (92% control), glyphosate (91% control), and aminopyralid (84% control), all of which were similar. At 4 MAT, few differences were detected among treatments with the exception of triclopyr, which provided greater control than glufosinate. Throughout the next 3 mo, triclopyr continued to provide higher control than all other treatments, and few differences were noted among aminopyralid, fluroxypyr, glyphosate, and glufosinate. During the second year in which data were taken up to 8 MAT, triclopyr had the highest mean control rating (83%), but fluroxypyr provided statistically similar control (65%). All other treatments were less efficacious than triclopyr.

At TSP where the SLSW infestation was more densely growing, triclopyr (93% control) and fluroxypyr (84% control) provided a similar level of control at 1 MAT, similar to results at PPP. However, at 1 MAT, glufosinate (94%) provided a statistically similar level of control and these three treatments

Table 4.—Efficacy of selected postemergence herbicides on small-leaf spiderwort in field experiments at Payne's Prairie (Gainesville, Florida) and Torreya State Park (Bristol, Florida). Results for Payne's Prairie are pooled over two separate experiments in different years. Data collected at 2, 7, and 8 MAT (months after treatment) were only collected in year 2. Herbicide rates are presented in kg active ingredient (ai) or acid equivalent (ae) per hectare. Percent control (and standard error) based on shoot visual control ratings in comparison with non-treated control groups. Means within columns followed by the same letter are not significantly different according to Fisher's protected LSD ($P = 0.05$).

Herbicide	Rate (kg ha^{-1})	Percent control							
		1MAT	2MAT	3MAT	4MAT	5MAT	6MAT	7MAT	8MAT
		Payne's Prairie Preserve							
Aminopyralid	0.12 ai	79 (5) c	78 (5) c	84 (6) bc	90 (5) ab	71 (6) cd	75 (4) b	50 (4) c	50 (4) b
Fluroxypyr	0.28 ai	100 (0) a	91 (1) b	92 (2) b	86 (9) ab	85 (5) b	76 (7) b	73 (4) b	65 (5) ab
Glufosinate	1.68 ai	90 (8) b	85 (2) bc	75 (7) c	69 (16) b	68 (7) d	55 (12) b	59 (5) bc	45 (11) b
Glyphosate	3.4 ai	94 (2) b	84 (4) c	91 (3) b	89 (7) ab	84 (4) bc	66 (9) b	70 (6) b	59 (7) b
Triclopyr	3.4 ae	100 (0) a	98 (1) a	98 (1) a	98 (1) a	97 (1) a	97 (1) a	89 (3) a	83 (3) a
		Torreya State Park							
Aminopyralid	0.12 ai	38 (6) c	—	70 (14) c	46 (9) b	40 (8) c	—	—	—
Fluroxypyr	0.28 ai	84 (8) ab	—	91 (3) ab	75 (4) b	68 (1) b	—	—	—
Glufosinate	1.68 ai	94 (1) a	—	93 (1) ab	69 (7) b	55 (13) bc	—	—	—
Glyphosate	3.4 ai	78 (5) b	—	76 (6) bc	68 (5) b	59 (8) bc	—	—	—
Triclopyr	3.4 ae	93 (1) a	—	99 (1) a	99 (1) a	91 (1) a	—	—	—

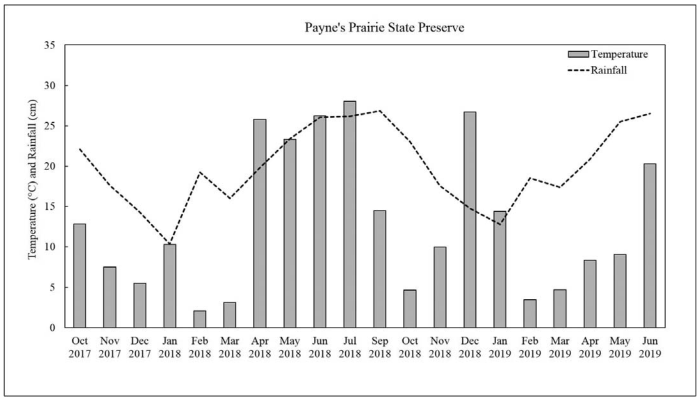

Figure 3.—Average monthly temperature (°C) and rainfall (cm) at Payne's Prairie Preserve in Gainesville, Florida, related to field experiments in 2018 and 2019. Data is shown for the duration of the experiments (January 2018 through June 2019) and for 3 mo prior to experiment initiation. Data were derived from the Florida Automated Weather Network (FAWN) Putnum Hall weather station, located approximately 15 miles from the experimental location.

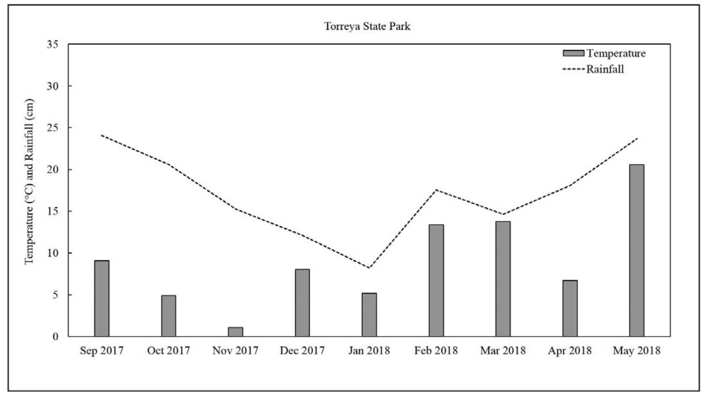

Figure 4.—Average monthly temperature (°C) and rainfall (cm) at Torreya State Park in Bristol, Florida, over the course of field experiments in 2017 and 2018. Data is shown for the duration of the experiments (December 2017 to May 2018) and for 3 mo prior to experiment initiation. Data were derived from the Florida Automated Weather Network (FAWN) Quincy weather station, located approximately 20 miles from the experimental location.

were the most effective. At this time, aminopyralid provided less control than any other treatment (38% control). Similar results were observed at 3 MAT. By 4 MAT, regrowth was observed in all treatments and with the exception of triclopyr (99% control), no herbicide provided greater than 75% control, and there was no difference in SLSW control treated with aminopyralid, fluroxypyr, glufosinate, or glyphosate. Triclopyr was again the most efficacious herbicide at 5 MAT and few other differences were noted among treatments. The one exception was that fluroxypyr provided a higher level of control than aminopyralid, similar to results observed at PPP.

DISCUSSION AND CONCLUSIONS

In contrast to previous reports where plants are generally more sensitive to herbicides in greenhouse experiments compared with field experiments (Fletcher et al. 1990), SLSW control tended to be higher in field experiments in our studies, at least when comparing visual ratings (field experiments) and shoot dry weight reductions (greenhouse experiments) of plants that were not cut prior to treatment. The reason greater control was observed in field studies is unknown, but was likely due to the time of year field experiments were conducted. At both locations in both years, experiments were initiated during the winter (2017–2018 experiments) or fall season (2018–2019). With the exception of the experiment at PPP initiated in September 2019, treatments coincided with cooler temperatures and lower rainfall, both of which lead to slower SLSW growth and regeneration (Dugdale et al. 2015) (Figures 3 and 4). In contrast, SLSW in greenhouse experiments were irrigated every day, probably contributing to greater growth and thus lower observed control due to recovery. While the efficacy of spring or summer applied treatments in Florida cannot be deduced from the current study, the high level of control observed following fall/winter applications could potentially be implemented as a strategic management strategy in Florida. That is, applications could be made to SLSW when it is most vulnerable to environmental conditions in Florida and possibly allow regeneration of cool season natives, which may limit SLSW encroachment as temperatures and rainfall rise during the warmer seasons.

In greenhouse experiments, pre-cutting SLSW increased herbicide efficacy, but this was not observed in field experiments, probably because SLSW roots were not constrained in the field and the population was growing more densely. Another potential factor that may have reduced the efficacy of pre-cutting in the field was that, unlike greenhouse experiments in which plants were allowed to regrow for 7 d, plants were immediately treated with herbicide after cutting in the field, potentially reducing leaf area and herbicide translocation (Duke 2018). Due to high labor and time requirement to implement this strategy, in addition to it resulting in no improvement in control, pre-cutting SLSW, at least immediately prior to treatment, would not be recommended in the field. Future research is needed to determine if other cutting and treatment timings could be implemented to increase efficacy.

Overall, both greenhouse and field data suggest triclopyr was the most effective herbicide evaluated for control of SLSW in Florida. Similar to results reported by Hurrell et al. (2009) and McCluggage (1998), we observed over 90% control of SLSW for up to 5 mo after application at two different locations in Florida and over 80% control at 8 MAT at one location. As rates lower than 3.4 kg ae ha^{-1} were not evaluated in the field, it is unknown how efficacious lower rates would be on mature SLSW populations in the field. However, because the 1.7 kg ae ha^{-1} rate was effective in greenhouse trials, future research is warranted to determine the efficacy of lower rates of triclopyr on mature populations of SLSW in field situations as they could potentially mitigate nontarget damage. As for the other herbicides that were evaluated, aminopyralid probably has the least utility as a management option for SLSW control. While aminopyralid performed similarly to several other treatments both in greenhouse and field trials, it was the only herbicide evaluated in field experiments that was applied at the maximum annual dose, thus repeat applications could not be made, and efficacy was lower than that observed with other herbicides on several evaluation dates.

Fluroxypyr had not previously been evaluated for control of SLSW, but tended to perform similarly to triclopyr at early evaluation dates and was the only treatment providing the same level of control as triclopyr at 8 MAT at the PPP location. Similarly, glufosinate had not been previously evaluated, but provided the same level of control as triclopyr in greenhouse trials and in field experiments at early evaluation dates at TSP. As less literature is available on these two herbicides in regard to SLSW management, additional research is warranted to investigate the efficacy of sequential applications, as both herbicides could potentially provide advantages in terms of mitigating nontarget plant damage.

Glyphosate provided poor control in greenhouse experiments and moderate SLSW control at PPP compared with lower control observed at TSP, most likely because the SLSW population at TSP was more densely growing. Variable results have been reported with glyphosate in previous studies ranging from over 95% control (McCluggage 1998) to virtually no control (Kelly and Skipworth 1984a). Similar to glufosinate and fluroxypyr, additional research is warranted with glyphosate to determine how application timing and use rate, as well as population density, influence SLSW control. With all herbicides, further work is needed to determine how sequential applications and rotation of herbicide mode of action can be implemented to develop long-term management approaches to SLSW while mitigating nontarget damage to native species.

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