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Cut-stem treatments using graminicides for burmareed (*Neyraudia reynaudiana*) invasions in Pine Rocklands, South Florida, USA

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Abstract

Burmareed [*Neyraudia reynaudiana* (Kunth) Keng ex Hitchc.] is an aggressive invader of pine rockland communities in south Florida. Currently, it is managed by clipping the stems and later returning, when plants have regrown to approximately 50 cm in height, to administer applications of glyphosate to new foliar growth (a "cut–return–treat," or CRT, strategy). This multi-visit strategy is time-consuming and may result in off-target effects due to the broad-spectrum nature of glyphosate. With this study we evaluated a cut-stem (CS) approach, in which stems are cut and immediately treated with herbicide. Further, we tested the efficacy of the selective graminicides sethoxydim and fluazifop-*P*-butyl. In a pot study, CS treatments included: glyphosate (239.7 g ae L^{-1}) in water, sethoxydim (9.0 g ai L^{-1}) or fluazifop-*P*-butyl (12.1 g ai L^{-1}) in either basal oil or water, and triclopyr (47.9 g ae L^{-1}) in basal oil. All CS treatments provided mortality and growth reduction comparable to the best CRT treatments (glyphosate, sethoxydim, and fluazifop-*P*-butyl) and were therefore evaluated under field conditions using the same application rates. Mortality was low in the field (≤30%) regardless of herbicide treatment. Overall, fluazifop-*P*-butyl provided greater control than sethoxydim, resulting in 71% and 94% relative growth reduction in total shoot length with oil and water carriers, respectively, compared with 50% and 43% reduction for sethoxydim. Fluazifop also provided control similar to triclopyr and glyphosate (≥65% reduction in total shoot length). Results suggest that CS treatments may be a viable strategy for managing *N. reynaudiana* and reducing management costs. However, more research is needed to optimize rates. Further, fluazifop-*P*-butyl allows for a more selective option than glyphosate that may decrease off-target effects on native understory vegetation in pine rocklands.

Introduction

Pine rocklands are species-rich habitats unique to southern Florida (Jones and Koptur 2017; Possley et al. 2014). These communities are characterized by an open canopy of Florida slash pine (*Pinus elliottii* Engelm. var. *densa* Little & Dorman) and a diverse understory of palms, shrubs, and herbaceous species (Jones and Koptur 2017; Williams et al. 2007). The combined pressures of human development and fire suppression have altered and reduced these rare ecosystems from ∼75,000 ha pre–European settlement to <10,000 ha today (Possley et al. 2014; Williams et al. 2007). The majority of pine rockland habitat (∼8,000 ha) is confined to the Everglades National Park; remaining habitat is highly fragmented within urban areas, where it is threatened by fire suppression and the encroachment of invasive plant species (Jones and Koptur 2017; Possley et al. 2014). A recent survey of pine rockland vegetation within Miami-Dade County determined that 19% of taxa were nonnative, and roughly half of these were considered invasive by the Florida Exotic Pest Plant Council (FLEPPC 2009; Possley et al. 2014). These invasive species exclude native plant communities and may alter fire regimes (Platt and Gottschalk 2001; Wolcott et al. 2007).

Burmareed [*Neyraudia reynaudiana* (Kunth) Keng ex Hitchc.] is native to subtropical regions of Southeast Asia; it is a tall woody graminoid (to 5 m) that can be easily mistaken for other large grasses (i.e., *Phragmites* spp.). The species was introduced to Coconut Grove, FL, in 1916 for ornamental evaluation by the U.S. Department of Agriculture (Gordon 1998; Gordon and Thomas 1997; Langeland et al. 2008). It is known to be a prolific seeder and subsequently escaped cultivation. By 1993 it was documented in nearly 75% of pine rocklands within Miami-Dade County (Langeland et al. 2008; Maguire 1993). *Neyraudia reynaudiana* suppresses native plant growth due to its height, phalanx growth form, and ability to grow into

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Management Implications

The critically imperiled pine rocklands in south Florida are threatened by urban development, fire suppression, and invasive species. *Neyraudia reynaudiana* (burmareed) is an aggressive invader in these communities and requires frequent management. Currently, managers utilize a "cut–return–treat" (CRT) approach, in which crews cut stems to ground level and return several weeks later to treat regrowing foliage with glyphosate. This method requires multiple site visits and relies on a nonselective herbicide (glyphosate). In this study, we compared a one-visit "cut-stem" (CS) approach (in which stems are removed and the cut surfaces are immediately treated with herbicide) to the CRT method. We evaluated the efficacy of glyphosate as well as more selective herbicides (the graminicides sethoxydim and fluazifop-*P*-butyl, as well as triclopyr), and evaluated the ability to use basal oil as a carrier for the two graminicides.

In a pot study, CS treatments performed as well as CRT treatments on *N. reynaudiana*. By reducing the number of required site visits per *N. reynaudiana* stand, the CS method may allow managers to spend more time searching for new recruits. CS treatments were also effective at reducing growth of *N. reynaudiana* in the field for the duration of the experiment (1 yr), but mortality was low, and further research is required to optimize application rates. The graminicides provided control comparable to glyphosate in both the CS and CRT treatments, with fluazifop-*P*-butyl providing slightly better control than sethoxydim in CS treatments in the field. Triclopyr also reduced growth of *N. reynaudiana* in both the field and pot studies. The use of these selective herbicides may help limit collateral damage to native species using either management method. Basal oil was an effective carrier of sethoxydim and fluazifop-*P*-butyl, although its use did not enhance efficacy compared with using water.

monotypic stands (Langeland et al. 2008; Platt and Gottschalk 2001). It produces high levels of fine litter fuels that accelerate fire cycles, having a catastrophic effect on native species such as young Florida slash pine (*P. elliottii* var. *densa*) in pine rockland communities (Platt and Gottschalk 2001).

Large *N. reynaudiana* can be difficult to manage within pine rocklands when trying to prevent collateral damage to rare and endemic species. Managers currently integrate mechanical removal with herbicide applications to control this grass: crews cut the stems to ground level and return several weeks later when plants have regrown to approximately 50 cm in height to spot treat the foliage with glyphosate (a "cut–return–treat," or CRT, approach) (Possley et al. 2018). While effective, this method is labor-intensive due to multiple site visits; furthermore, there is a risk that management crews may miss plants on their return visit. There is also a risk of overspray with foliar treatments, which can potentially result in off-target effects on desirable species. A "cut-stem" (CS) method, in which stems are hand-cut and the cut surfaces are immediately treated with herbicide, has been used with success on another invasive cane grass species (common reed [*Phragmites australis* (Cav.) Trin. ex Steud.]) (Breen et al. 2014; Lombard et al. 2012). Breen et al. (2014) found that the CS treatments were equally effective in controlling *P. australis* as typical foliar treatments. If also effective on *N. reynaudiana*, this method has the potential to reduce the number of necessary site visits per plant, allowing managers to spend more time searching for new recruits, while also minimizing off-target damage. In addition, although CS treatments typically use higher concentrations of herbicide than foliar treatments, they require a much lower volume of product and can potentially reduce chemical inputs into the ecosystem as well. Therefore, there is a need to evaluate the relative efficacy of CS treatments and current management strategies on *N. reynaudiana* stands in pine rocklands.

In addition, there is a need to evaluate selective products. Glyphosate is often used for management of *N. reynaudiana* in pine rocklands (Possley et al. 2018), but due to its broad-spectrum nature, its use can result in off-target effects on other species. Using graminicides such as sethoxydim and fluazifop-*P*-butyl may greatly reduce collateral damage to native understory species in the vicinity. There is a need to evaluate the efficacy of these herbicides on *N. reynaudiana*. Foliar absorption of both sethoxydim and fluazifop-*P*-butyl is enhanced by the addition of oil-based adjuvants, but to our knowledge these products have not yet been evaluated with a basal oil carrier (Chandrasena and Sagar 1986; Nalewaja and Skrzypczak 1986). Therefore, there is also an opportunity to evaluate oil-based carriers that may enhance efficacy of CS treatments using these herbicides.

Here, we compared the efficacy of the CS treatments to the current conventional CRT technique on *N. reynaudiana* grown in pots. We further evaluated CS treatments on well-established *N. reynaudiana* stands in the pine rocklands. We compared glyphosate with more selective herbicides (the graminicides sethoxydim and fluazifop-*P*-butyl, as well as triclopyr), and evaluated the ability to use basal oil as a carrier for the two graminicides.

Materials and Methods

Pot Study

A pot study was conducted at the nursery of Fairchild Tropical Botanic Garden in Coral Gables, FL, located at the Montgomery Botanical Center (25.6602°N, 80.28296°W). One hundred root crowns of *N. reynaudiana* were collected from Zoo Miami (Miami, FL) for use in the experiment. Canes were cut to a standard size (10 cm) and planted in 11.4-L pots filled with commercial potting soil (Sun Gro® Fafard® 3B Mix/Metro-Mix 830, Sun Gro Horticulture, 770 Silver Street, Agawam, MA 01001) and slow-release fertilizer (Osmocote® Classic 14-14-14, 4.84 g L^{-1}, Scotts Company, 14111 Scottslawn Road, Marysville, OH 43041). Pots were watered daily. After 6 mo of growth, 84 pots were selected as experimental units and blocked ($n = 7$) based on total shoot length before herbicide application. Blocks were evenly, randomly divided for CS and CRT treatments.

Herbicide treatments for CS and CRT applications are displayed in Table 1. Stems of all plants were cut to 10 cm above the soil level using pruning shears on June 27, 2017. There were seven replicates per treatment. For CS treatments, the cut surfaces of stems were treated immediately with herbicide. Three carriers were evaluated with herbicide treatments; sethoxydim and fluazifop-*P*-butyl treatments were blended with either water or basal oil (Bark Oil Blue, Loveland Products, 3005 Rocky Mountain Avenue, Loveland, CO 80538), glyphosate treatments were diluted in water, and triclopyr ester was blended with a different basal oil (Impel Red, Helena Chemical, 225 Schilling Boulevard, Collierville, TN 38017). Approximately 1 ml of treatment solution was dribbled using minimal pressure onto each cut stem using a 1.5-L handheld pressurized sprayer with an

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Table 1. Herbicide treatments from the pot and field studies.

Method[a]	Common name	Trade name	Herbicide manufacturer	Rate	Carrier	Experiment
CS	Sethoxydim	Poast®	BASF Corporation, Research Triangle Park, NC https://www.basf.com	9.0 g ai L^{-1}	Water	Pot study, field study
					Basal oil	Pot study, field study
CS	Fluazifop-*P*-butyl	Fusilade® II	Syngenta, Greensboro, NC https://www.syngenta-us.com	12.1 g ai L^{-1}	Water	Pot study, field study
					Basal oil	Pot study, field study
CS	Glyphosate	Rodeo®	Dow Agrosciences, Indianapolis, IN https://www.dowagro.com/en-us	239.7 g ae L^{-1}	Water	Pot study, field study
CS	Triclopyr ester	Garlon® 4 Ultra	Dow Agrosciences, Indianapolis, IN https://www.dowagro.com/en-us	47.9 g ae L^{-1}	Basal oil	Pot study, field study
CRT	Sethoxydim	Poast®		2.7 g ai L^{-1}	Water	Pot study
CRT	Sethoxydim	Poast®		9.0 g ai L^{-1}	Water	Pot study
CRT	Fluazifop-*P*-butyl	Fusilade® II		1.2 g ai L^{-1}	Water	Pot study
CRT	Fluazifop-*P*-butyl	Fusilade® II		12.1 g ai L^{-1}	Water	Pot study
CRT	Glyphosate	Rodeo®		24.0 g ae L^{-1}	Water	Pot study
Cut only	Untreated			–	–	Pot study, field study

[a] CRT, cut–return–treat; CS, cut-stem.

adjustable cone nozzle. Although some herbicide ran down the sides of stems, full coverage of each cut surface was achieved.

For CRT treatments, plants were allowed to regrow for 1 mo to an average height of 17 cm before treatment on July 27, 2017. Total shoot length was recorded before treatment. Foliar applications were made using a pressurized backpack sprayer at an average rate of 863 L ha^{-1}. All treatments included a methylated seed oil (MSO) adjuvant (MSO Concentrate with Leci-Tech, 1% v/v, Loveland Products). For the control treatment, stems were cut to pot level but were not treated with herbicide. The length of time required for treatment was recorded for each plant and used to calculate the volume of herbicide that was applied. The volume of applied herbicide was plotted against the total shoot length at the time of treatment for both CS and CRT treatments. The amount of herbicide applied per stem for CS treatments was not recorded for the pot study, but estimations were made using values from the field study where we applied an average of 0.76 ml per stem. Shoot length (cm), shoot number, and mortality (%) were recorded on October 23, 2017 (16 wk after cutting [WAC]). To determine aboveground biomass (g), shoots were harvested and dried at 65 C in a forced-air drying oven until a constant weight was reached.

Field Study

A field study was initiated at Zoo Miami in Miami, FL (25.611484°N, 80.398010°W), to further evaluate the CS treatments. There were two experimental runs, each with thirty-five 1-m^2 plots: the first experimental run was established and treated on November 11, 2017, and the second was established and treated on December 8, 2017. Plots were blocked by total number of live canes. Canes were cut to 10 cm in height using pruning shears. Herbicide treatments (with five replicates each) were applied using the same CS methods as in the pot study and with the same combinations of herbicides and carriers (Table 1). The number and total length (cm) of all live shoots were recorded at 6 and 12 mo after treatment (MAT). Mortality (%) of plants and oven-dried aboveground biomass of live shoots were also recorded at 12 MAT.

Statistical Analysis

All pot and field experiments were conducted as randomized complete block designs. Mortality data were analyzed using binomial logistic regression via the *glm* function in R software (R Core Team 2018) using RStudio (RStudio Team 2016). Data for the volume of herbicide applied using CS and CRT methods were analyzed using linear regression. For all other measured parameters, relative growth reduction (RGR) was calculated using the values for the untreated controls:

$$\mathrm{RGR} = 100 \times \frac{\text{untreated plants} - \text{treated plants}}{\text{untreated plants}} \qquad [1]$$

Percent reduction data were then analyzed using one-way ANOVA. Fisher's LSD was conducted using the AGRICOLAE package (de Mendiburu 2017) to determine mean separation at $P < 0.05$. Residuals were tested for assumptions of normality and homogeneity of variance, and logarithmic transformations were performed as necessary. For the field study, there was no run effect ($P < 0.05$), so data were pooled between experimental runs.

Results and Discussion

Pot Study

In the pot study, the volume of applied herbicide solution applied increased with total shoot length (Figure 1). This relationship was significant for both CRT ($P = 0.03$) and CS ($P = 0.01$) treatments. The volume applied per total shoot length was much higher for CRT compared with CS treatments (1,590 ml – 3,792 ml vs. 4.5 ml – 23 ml, respectively). This suggests that CS treatments have the potential to greatly reduce the volume of herbicide used in *N. reynaudiana* management. Further, nearly all CS treatments resulted in 100% mortality at 16 WAC (Table 2). Untreated controls had an average of 13.4 shoots, were 121 cm in height, and had an aboveground biomass of 98.3 g per pot; only sethoxydim in water did not result in 100% mortality or relative growth reductions compared with the untreated controls. However, the level of control provided by this treatment was still high (i.e., ≥85% mortality and reductions in growth), and was similar to other CS treatments. For sethoxydim and fluazifop, there were no differences between treatments using water or basal oil as carriers.

Of the CRT treatments, only the highest application rate of fluazifop-*P*-butyl (12.1 g ai L^{-1}) provided 100% reduction in growth characteristics and mortality ratings greater than 85%

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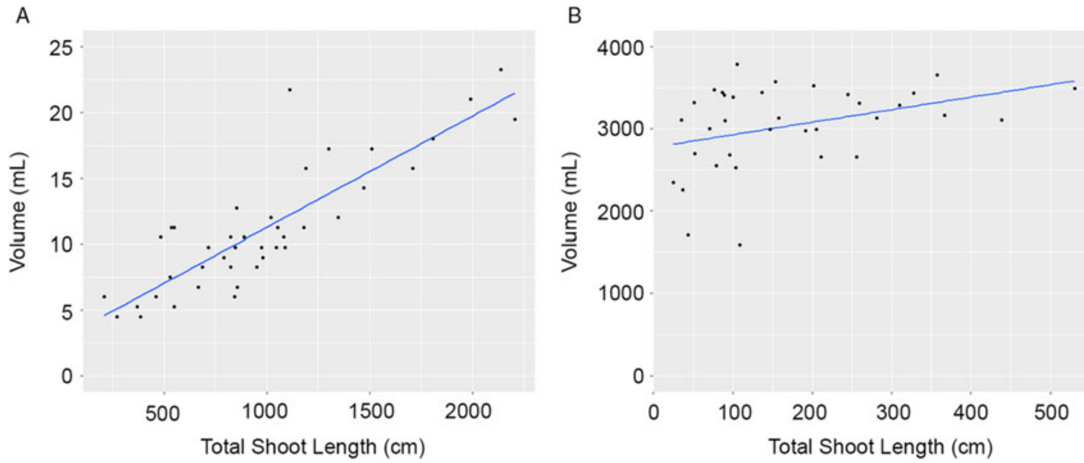

Figure 1. The volume of herbicide solution (ml) applied per *Neyraudia reynaudiana* plant plotted against total shoot length (cm) for (A) cut-stem (CS) treatments ($y = 0.008x + 2.8$; $R^2 = 0.73$) and (B) cut–return–treat (CRT) treatments ($y = 1.5x + 2{,}776.9$; $R^2 = 0.14$).

Table 2. Relative growth reduction (RGR) (±SE) of shoot number, height, and aboveground biomass, as well as mortality of *Neyraudia reynaudiana* at 16 wk after cutting in the pot study.[a]

Herbicide	Carrier	Method[b]	Stem number	Height	Aboveground biomass	Mortality
			RGR[c] (%)			%
Sethoxydim	Basal oil	CS	100 ± 0 (a)	100 ± 0 (a)	100 ± 0 (a)	100 ± 0 (a)
Sethoxydim	Water	CS	93.6 ± 6.4 (a)	96.6 ± 3.4 (ab)	99.4 ± 0.6 (a)	85.7 ± 14.3 (ab)
Fluazifop	Basal oil	CS	100 ± 0 (a)	100 ± 0 (a)	100 ± 0 (a)	100 ± 0 (a)
Fluazifop	Water	CS	100 ± 0 (a)	100 ± 0 (a)	100 ± 0 (a)	100 ± 0 (a)
Glyphosate	Water	CS	100 ± 0 (a)	100 ± 0 (a)	100 ± 0 (a)	100 ± 0 (a)
Triclopyr	Basal oil	CS	100 ± 0 (a)	100 ± 0 (a)	100 ± 0 (a)	100 ± 0 (a)
Sethoxydim	Water	CRT	−78.7 ± 35.9 (c)	50.3 ± 11.5 (c)	75.2 ± 7.2 (c)	0 ± 0 (c)
Sethoxydim	Water	CRT	69.2 ± 18.1 (ab)	89.4 ± 5.3 (ab)	97.6 ± 1.7 (a)	57.1 ± 20.2 (abc)
Fluazifop	Water	CRT	26.6 ± 19.7 (b)	88.1 ± 2.5 (ab)	93.7 ± 3.5 (ab)	14.3 ± 14.3 (c)
Fluazifop	Water	CRT	100 ± 0 (a)	100 ± 0 (a)	100 ± 0 (a)	85.7 ± 14.3 (ab)
Glyphosate	Water	CRT	50.6 ± 26 (ab)	79.7 ± 7.4 (b)	87.4 ± 3.5 (b)	28.6 ± 18.4 (bc)
Untreated	–	–	–	–	–	0 ± 0 (c)

[a] Letters within a column indicate significance ($P \leq 0.05$); values followed by different letters are significantly different.
[b] Plants were treated using either a cut-stem (CS) or cut–return–treat (CRT) method.
[c] RGR was calculated using Equation 1: $\mathrm{RGR} = 100 \times \frac{\text{untreated plants} - \text{treated plants}}{\text{untreated plants}}$.

(Table 2). The lowest application rate of fluazifop-*P*-butyl (1.2 g ai L^{-1}) resulted in low mortality and percent reductions in shoot number (14% ± 14% and 27% ± 20%, respectively), but relatively high reductions in height and aboveground biomass (≥90%). The CRT glyphosate treatment resulted in a reduction in shoot number similar to those of the CS treatments but lower percent reductions in height and aboveground biomass, as well as a mortality rating that was not different from those of the untreated controls. The highest CRT rate of sethoxydim (9.0 g ai L^{-1}) resulted in values similar to those of the CS treatments across measured characteristics, although the lowest application rate (2.7 g ai L^{-1}) provided less control and 0% mortality.

Results from the pot study suggest that CS treatments perform as well as CRT treatments at controlling *N. reynaudiana*, while also greatly reducing the required volume of chemical input. When compared with several CRT treatments, such as the lower application rates of sethoxydim and fluazifop-*P*-butyl, CS treatments resulted in better control in terms of mortality and reduction in growth. These results are consistent with previous research by Breen et al. (2014), who found that CS treatments using imazapyr were equally effective compared with traditional foliar spraying in controlling *P. australis*. We did not evaluate imazapyr in this study due to concerns surrounding potential off-target damage; however, future research should also evaluate efficacy of imazapyr in CS treatments on *N. reynaudiana*.

Importantly, CRT treatments with fluazifop-*P*-butyl and sethoxydim provided control comparable to that of glyphosate, the current standard for *N. reynaudiana* management. Both

Table 3. Relative growth reduction (RGR) (±SE) of shoot number and total shoot length of *Neyraudia reynaudiana* at 6 mo after treatment using the cut-stem (CS) method in the field experiment.

Herbicide	Carrier	Shoot number	Total shoot length
		RGR[a] (%)	
Fluazifop	Basal oil	81.3 ± 9.4 (a)	82.4 ± 10 (ab)
Fluazifop	Water	90.5 ± 2.7 (a)	94.3 ± 2.3 (a)
Triclopyr	Basal oil	84.3 ± 5.5 (a)	86.1 ± 6 (a)
Glyphosate	Water	37.8 ± 36.7 (bc)	64.6 ± 22.2 (abc)
Sethoxydim	Basal oil	51.0 ± 8.4 (abc)	52.1 ± 12.4 (bc)
Sethoxydim	Water	23.3 ± 13.2 (c)	41.5 ± 5.8 (c)

[a] RGR was calculated using Equation 1: $\mathrm{RGR} = 100 \times \frac{\text{untreated plants} - \text{treated plants}}{\text{untreated plants}}$. Letters within a column indicate significance ($P \leq 0.05$); values followed by different letters are significantly different.

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Table 4. Relative growth reduction (RGR) (±SE) of aboveground biomass, shoot number, and total shoot length of *Neyraudia reynaudiana* at 12 mo after treatment using the cut-stem (CS) method in the field experiment.[a]

Herbicide	Carrier	Aboveground biomass	Shoot number	Total shoot length	Mortality
		RGR[b] (%)			%
Fluazifop	Basal oil	91.6 ± 5.3 (ab)	34.3 ± 28.2 (a)	71.3 ± 15.4 (ab)	20 ± 13 (a)
Fluazifop	Water	98 ± 0.8 (a)	59.3 ± 13.7 (a)	93.5 ± 2.1 (a)	30 ± 15 (a)
Triclopyr	Basal oil	85.6 ± 6.5 (ab)	37.1 ± 16.4 (a)	72.2 ± 11.4 (ab)	0 ± 0 (a)
Glyphosate	Water	91.1 ± 4.9 (ab)	−20.7 ± 52.4 (ab)	65.6 ± 16.3 (ab)	30 ± 15 (a)
Sethoxydim	Basal oil	76.5 ± 6.4 (b)	−57.1 ± 36.8 (b)	49.5 ± 13.4 (b)	10 ± 10 (a)
Sethoxydim	Water	88.8 ± 2.4 (ab)	−97.1 ± 35.5 (b)	42.7 ± 8.7 (b)	0 ± 0 (a)
Untreated	–	–	–	–	0 ± 0 (a)

[a]Letters within a column indicate significance ($P \leq 0.05$); values followed by different letters are significantly different.
[b]RGR was calculated using Equation 1: $\mathrm{RGR} = 100 \times \frac{\text{untreated plants} - \text{treated plants}}{\text{untreated plants}}$.

fluazifop-*P*-butyl and sethoxydim are grass-specific herbicides; their ability to effectively control *N. reynaudiana* provides managers with more selective options than glyphosate, if they choose to use CRT treatments. The use of these products may reduce off-target effects on broadleaf understory species in the pine rocklands, including federally listed threatened and endangered species such as Blodgett's silverbush [*Argythamnia blodgettii* (Torr.) Chapm.] and wedge sandmat [*Chamaesyce deltoidea* (Engelm. ex Chapm.) Small ssp. *deltoidea*] (Possley et al. 2018; USFWS 1985, 2016).

Field Study

Given the success of CS treatments in the pot study, we evaluated these treatments in the field to test efficacy on naturalized *N. reynaudiana*. At 6 MAT, fluazifop-*P*-butyl (in basal oil or water) resulted in the greatest reductions (≥80%) in shoot number and total shoot length compared with the untreated controls (which had an average of 40 shoots and total shoot length of 263.5 cm) (Table 3). However, sethoxydim in basal oil resulted in a reduction in shoot number (51% ± 8.42%) similar those of these treatments, and glyphosate resulted in a similar reduction in the total shoot length (65% ± 22%). Sethoxydim in water resulted in the lowest reductions in shoot number and total shoot length (23% ± 13% and 41% ± 6%, respectively); these reductions were less than those caused by fluazifop-*P*-butyl and triclopyr, but not different from those caused by sethoxydim in basal oil or glyphosate.

At 12 MAT, all herbicide treatments resulted in high reductions (≥75%) in aboveground biomass compared with the untreated controls (which had an average aboveground biomass of 421.6 g m^{-2}, 36.7 shoots, and total shoot length of 592.74 cm) (Table 4). Fluazifop-*P*-butyl (in water or oil), triclopyr, glyphosate, and sethoxydim in water resulted in similar reductions in aboveground biomass. Sethoxydim in basal oil produced lower reductions in aboveground biomass than fluazifop-*P*-butyl in water, but results were similar to those of all other treatments. Glyphosate and sethoxydim (in water or oil) resulted in an increase in shoot number compared with untreated controls (Table 4); this is a common symptom of sublethal herbicide applications. While fluazifop-*P*-butyl and triclopyr did decrease shoot number compared with untreated controls, percent reduction was relatively low (≤60%) across all treatments. Sethoxydim (in water or oil) resulted in the lowest reduction of total shoot length. Mortality was low across all treatments, and there were no differences between herbicides (Table 4).

Overall, few differences were found between herbicides or carriers in the field. Although the basal oil carriers did not significantly enhance graminicide activity in CS treatments, results indicate compatibility with sethoxydim and fluazifop-*P*-butyl. Further, evidence suggests that fluazifop-*P*-butyl may provide greater suppression of *N. reynaudiana* than sethoxydim, particularly when water is used as a carrier. Fluazifop-*P*-butyl also provided similar or better control than the standard glyphosate across all measured parameters; use of this product provides managers with a more selective tool for treating *N. reynaudiana* in pine rocklands.

CS treatments were more effective on *N. reynaudiana* in the pot study than in the field experiment, particularly when using sethoxydim. This may be due to the growing conditions in each experiment; plants grown under controlled conditions can exhibit increased sensitivity to herbicides due to environmental factors or reduced rhizome biomass caused by limited photosynthetic rates or pot confinement (Riemens et al. 2008; Spencer et al. 2011). However, differences may also result from a seasonal effect, as plants were treated during the summer in the pot study and during the fall in the field. Research on other cane grasses, such as *P. australis* and giant reed (*Arundo donax* L.), has demonstrated that application timing can greatly affect management success (Mozdzer et al. 2008; Spencer et al. 2011). More research is needed to determine the optimum treatment time for *N. reynaudiana* using the CS method and to investigate higher application rates in the field.

Interestingly, triclopyr was highly effective on *N. reynaudiana* in both pot and field studies. Triclopyr is primarily used for broadleaf and woody species; its efficacy on monocots is generally low. However, it has been shown to have moderate phytotoxicity on barley (*Hordeum vulgare* L.), creeping bentgrass (*Agrostis stolonifera* L.), and kikuyugrass (*Pennisetum clandestinum* Hochst. ex Chiov.), and to suppress seedling development of certain grass species (Cudney et al. 1993; Dernoeden et al. 2008; Huffman and Jacoby 1984; Lewer and Owen 1990; Shaner 2014). Application rate is known to have an effect on selectivity of certain herbicides; e.g., glyphosate is a broad-spectrum herbicide, but at low use rates can exhibit selectivity toward more sensitive species (Kyser et al. 2012). The rate used in this study (47.9 g ae L^{-1}) was high; further research should be considered to determine the limits of *N. reynaudiana* tolerance to triclopyr.

These results suggest that the CS application method may be an effective approach for controlling *N. reynaudiana*. The ability to use CS treatments instead of foliar CRT applications may reduce the effort needed to manage *N. reynaudiana* by minimizing the need for return visits and may lessen collateral injury to surrounding native species. Further, the CS method is a more measured

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technique than CRT, presenting an opportunity to reduce the volume of chemical inputs into pine rockland communities. This work also suggests that more selective herbicides, such as sethoxydim and fluazifop-*P*-butyl, may be effective alternatives to glyphosate. However, given low mortality rates in the field, further research is needed to evaluate optimal application rates and address the effects of application timing for CS treatments. In addition, future research should evaluate the relative off-target effects of CS and CRT applications on native species in the field.

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