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Cadillo (*Urena lobata*) control with POST herbicides

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Research Article

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Abstract

Cadillo is an invasive species in Florida pastures and natural areas. Despite its invasiveness, relatively few studies have evaluated cadillo management. Thus, the objective of this research was to determine effective POST herbicides for cadillo control in Florida. Greenhouse and field studies were conducted at the Range Cattle Research and Education Center near Ona, FL, in 2015 and 2016. In the greenhouse study, triclopyr-ester, aminopyralid, metsulfuron, 2,4-D amine, aminopyralid + metsulfuron, aminocyclopyrachlor + metsulfuron, and imazapyr + aminocyclopyrachlor + metsulfuron provided ≥80% control of cadillo 28 d after treatment (DAT). Aminocyclopyrachlor at 17 and 35 g ha^{-1} were the only treatments with <80% control, with 70% and 75% control, respectively. Similar results were reflected in cadillo dry biomass reduction. The herbicide treatments used in the field study were triclopyr-ester, aminopyralid, 2,4-D amine, aminocyclopyrachlor, and triclopyr + fluroxypyr. Most treatments provided excellent control in the field (≥90% control) 30 DAT, and by 60 DAT all treatments provided 100% control. Results from these studies suggest that cadillo is susceptible to many of the common POST herbicides utilized in pastures and natural areas in Florida.

Introduction

Cadillo, also known as caesarweed, aramina, hibiscus burr, and jute africain (USDA 2018), is an annual herb in the Malvaceae family that behaves as a short-lived perennial under environmental conditions in Florida. Cadillo is originally from Asia, but it has spread throughout most tropical and subtropical regions of the world and is commonly found invading pastures, rangeland, poorly managed areas, and natural areas (Wang et al. 2009). Cadillo has the ability to grow over a wide range of altitudes and has been reported growing from near sea level to approximately 1,000 m above sea level (Awan et al. 2014). In addition, it thrives under a wide variety of soil types and can reach 3 m in height with woody stems at maturity (Francis 2003). Moreover, cadillo can produce up to 600 seeds per plant per year, and seed is the primary means of spread (Harris and Brewah 1986). Dispersion is aided by livestock or humans because of the barbed trichomes on the fruit capsule that cling to fur or clothing.

According to the Florida Exotic Pest Plant Council, cadillo is listed as a Category I species on the list of nuisance plants, implying that this species is increasing in number and causing ecological harm (FLEPPC 2017). Fagundes (2002) stated that this species has been found to be aggressive in nature, commonly causing severe infestations when not managed. Furthermore, the University of Florida Institute of Food and Agricultural Sciences Assessment of non-native plants in Florida's natural areas recommends against any agronomic use of this species throughout the entire state of Florida (UF/IFAS 2018).

Cadillo is frequently found infesting pastures of bahiagrass (*Paspalum notatum* Flueggé), the most widely used forage of cow/calf operations in Florida (Burton et al. 1997; Chambliss 1996). Even though the impacts of cadillo interference on bahiagrass have not been identified, the presence of cadillo in bahiagrass pastures probably reduces both forage productivity and availability, as has been observed with dogfennel [*Eupatorium capillifolium* (Lam.) Small] (Dias et al. 2018). This is especially relevant in that bahiagrass does not tolerate shading (Trenholm et al. 2015). Because heavy infestations of cadillo have been observed to create a dense canopy and affect bahiagrass production (BA Sellers, unpublished data), control options for this species are necessary.

Previous research on cadillo control is limited. Cadillo has been grown in Sierra Leone as a fiber crop (Harris 1981), and most of the research conducted on cadillo has focused on attempts to enhance plant growth rather than control it (Wang et al. 2009). Therefore, it is important to investigate the susceptibility of cadillo to different control management strategies, especially the use of herbicides.

Some of the herbicides most commonly used in permanent grass pasture systems in Florida include triclopyr, fluroxypyr, and aminopyralid (Abe et al. 2016; Sellers et al. 2009). These herbicides are classified as synthetic auxin herbicides and belong to the pyridine carboxylic acid family (Shaner 2014). Triclopyr has activity on broadleaf brush-type species such as blackberry (*Rubus* spp.) (Ferrell et al. 2009), dogfennel (MacDonald et al. 1994; Sellers et al. 2009), tropical soda apple (*Solanum viarum* Dunal) (Call et al. 2000), and southern waxmyrtle [*Morella cerifera* (L.) Small] (Kalmbacher et al. 1993). Aminopyralid (AMP) and fluroxypyr are used to control annual and perennial broadleaf weeds in permanent grass pastures, rangeland, and non-cropland areas (Shaner 2014). AMP is highly active on many invasive plant species such as Canada thistle [*Cirsium arvense* (L.) Scop.] (Enloe et al. 2007), tropical soda apple (Ferrell et al. 2006), Russian knapweed [*Rhaponticum repens* (L.) Hidalgo] (Enloe et al. 2008), and largeleaf lantana (*Lantana camara* L.) (Ferrell et al. 2012). In addition, fluroxypyr has been increasingly used in Florida because of its efficacy against dogfennel (MacDonald et al. 1994; Sellers et al. 2009), a very common broadleaf pasture weed in Florida (Sellers and Ferrell, 2016).

Given the need to identify effective chemical control options to reduce the spread of cadillo, the main objective of this research was to evaluate herbicides for effective POST control of cadillo in Florida pastures. We hypothesize that POST herbicides commonly used in Florida's pastures and natural areas will effectively control cadillo.

Materials and Methods

An initial greenhouse screening experiment was conducted to evaluate the effectiveness of various POST herbicides, applied either alone or in mixtures to control cadillo. Results from the greenhouse experiment were used to refine the treatments included in the field study.

Greenhouse Screening Study

Cadillo seeds were collected from various locations at the University of Florida Institute of Food and Agricultural Sciences Range Cattle Research and Education Center (RCREC), near Ona, FL (27.39° N, 81.94° W, 29 m altitude), in 2014. Immediately after collection, seeds were separated from undesired materials and stored in paper bags in the shade. Seed coats were physically broken by rubbing seeds between two wood blocks lined with sandpaper before planting into 5- by 5-cm pots uniformly filled with commercial potting medium (Fafard Mixes for Professional Use, Conrad Fafard Inc., Agawan, MA) amended with 14-14-14 slow-release fertilizer (Osmocote Smart-Release Plant Food, Scotts-Sierra Horticultural Products Co., Marysville, OH). Two seedings were made on May 6 and June 10, 2015. Pots were thinned to one plant per pot at the one-leaf growth stage. Plants were supplied with adequate water and kept in greenhouse conditions at 30 C day/24 C night temperature. Artificial lighting was provided to ensure a 14-h photoperiod.

POST herbicide treatments were applied approximately 30 d after seeding with a compressed air–powered moving-nozzle spray chamber (Generation II Spray Booth, Devries Manufacturing Corp., Hollandale, MN) equipped with a Teejet 8001 EVS spray nozzle (Teejet Technologies Southeast, Tifton, GA) calibrated to deliver 187 L ha^{-1} at 172 kPa. A list of herbicide treatments and rates is provided in Table 1. All treatments included a nonionic surfactant (Activator 90®, Loveland Products Inc., Greeley, CO 80632) at 0.25% v/v. Cadillo plants were at the five- to nine-leaf growth stage at time of application. Plants were returned to the greenhouse following herbicide treatment and maintained as previously described.

The experimental design was a randomized complete block design with six replications. Even though the experiment was conducted under controlled greenhouse conditions, plants were not uniformly sized; therefore, plants were blocked by size. A single pot served as the experimental unit. The cadillo control was visibly evaluated 14, 21, and 28 d after treatment (DAT). Visible comparisons of each treated pot to the nontreated control were made on a rating scale of 0 (no control) to 100% (complete absence of live cadillo leaves or stem) control. The cadillo control was also quantitatively assessed by clipping the aboveground biomass at the soil surface at 28 DAT, drying at 60 C for 72 h, and recording dry weights. Biomass data were converted into percent biomass reduction of the nontreated plants within each replication.

Field Study

Based on the results from the greenhouse experiments, field experiments were conducted with selected treatments at the RCREC near Ona, FL, in 2015 and 2016 (27.38° N, 81.94° W, 29 m altitude). The experiments were conducted on a pine (*Pinus elliotii* Engelm.)–bahiagrass silvopasture, and different locations within the same silvopasture were used in 2015 and 2016. The predominant soil type at both locations consisted of Ona fine sand (sandy siliceous, hyperthermic Typic Alaquods); soil pH was 4.8 and organic matter was 3.43% before initiation of the study. Monthly rainfall and yearly totals of 2015 and 2016 were obtained from the weather station located at the research center and are presented in Table 2.

Herbicide treatments were applied July 30, 2015 and August 16, 2016 with a tractor-mounted, compressed-air broadcast sprayer equipped with a 3-m boom with 8 flat-fan nozzles calibrated to deliver 233 L ha^{-1}. Plants were approximately 2 m tall at the time of application. Nonionic surfactant (Activator 90®, Loveland Products Inc., Greeley, CO 80632) was added to all treatments at 0.25% v/v. Treatments that contained metsulfuron were not included in the field experiments because of unacceptable injury to bahiagrass (Bunnell et al. 2003). Herbicide treatments and rates are listed in Table 3. A premix of triclopyr + fluroxypyr was included, as it is one of the most popular treatments currently utilized in Florida pastures for dogfennel management (Sellers and Ferrell 2016).

The experimental design was a randomized complete block design with four replications. Experimental plots were 6 m wide by 15 m long, and each plot was sprayed with two passes of the tractor. Control of established cadillo plants in the field was visibly evaluated 15, 30, and 60 DAT. Visible evaluations were made as previously described in the greenhouse experiments.

Data Analysis

Data were subjected to ANOVA using the "aov()" function in R (R Development Core Team 2008) to test for experimental run and herbicide treatment effects in the greenhouse experiment, and for year and herbicide treatment effects in the field experiment. Treatments and interactions were considered significant when $P \leq 0.05$. If interactions were not significant, data were pooled

Table 1. Herbicide treatments used in the greenhouse experiment.

Herbicide treatments	Rate g ae/ai ha^{-1}	Trade name	Manufacturer
Triclopyr-ester	280	Remedy Ultra (4.8 kg ae L^{-1})	Dow AgroSciences, Indianapolis, IN
	561		
	1,121		
Aminopyralid	61	Milestone (2.4 kg ae L^{-1})	Dow AgroSciences, Indianapolis, IN
	122		
Metsulfuron	11	Excort XP (60% w/w)	Du Pont Corp.,Wilmington, DE
	21		
2,4-D amine	561	Weedar 64 (4.55 kg ae L^{-1})	Nufarm Corp., Alsip, IL
	1,121		
	2,242		
Aminocyclopyrachlor	17	Method 50SG (50% w/w)	Du Pont Corp.,Wilmington, DE
	35		
	70		
Aminopyralid + metsulfuron	43 + 7	Chaparral TM (62.13% + 9.45% w/w)	Dow AgroSciences, Indianapolis, IN
	87 + 13		
	130 + 20		
Aminocyclopyrachlor + metsulfuron	125 + 40	Streamline R (39.5% + 12.6% w/w)	BAYER Corp., Research Triangle Park, NC
	263 + 84		
Imazapyr + aminocyclopyrachlor + metsulfuron	288 + 208 + 66	Viewpoint R (31.6% + 22.8% + 7.3% w/w)	Du Pont Corp.,Wilmington, DE
	443 + 319 + 102		

Table 2. Monthly rainfall at the Range Cattle Research and Education Center (RCREC) near Ona, FL, in 2015 and 2016.

	Rainfall		
Month	2015	2016	67-yr average
	mm		
January	41	153	54
February	87	48	66
March	28	27	79
April	98	24	62
May	42	83	94
June	228	264	221
July	205	165	212
August	380	134	211
September	114	124	186
October	43	47	78
November	29	4	49
December	53	16	52
Total	1,348	1,089	1,363

Table 3. Herbicide treatments used in field experiments.

Herbicide treatments	Rate g ae or ai ha^{-1}	Trade name
Triclopyr-ester	561 g ae ha^{-1}	Remedy Ultra (4.8 kg ae L^{-1})
	1,121 g ae ha^{-1}	
Aminopyralid	122 g ae ha^{-1}	Milestone (2.4 kg ae L^{-1})
2,4-D amine	1,121 g ae ha^{-1}	Weedar 64 (4.55 kg ae L^{-1})
	2,242 g ae ha^{-1}	
Aminocyclopyrachlor	35 g ai ha^{-1}	Method 50 SG (50% w/w)
	70 g ai ha^{-1}	
Triclopyr + fluroxypyr	420 + 140 g ae ha^{-1}	Pastureguard HL (3.6 kg ae L^{-1} of triclopyr + 1.2 kg ae L^{-1} of fluroxypyr)
	841 +280 g ae ha^{-1}	

across runs (greenhouse study) or years (field study). Normality, independence of errors, and homogeneity were visibly examined, and no transformations were necessary. Means were separated at $P \leq 0.05$ with Fisher's protected LSD test where the ANOVA indicated that treatment effects were significant.

Results and Discussion

Greenhouse Screening Study

There was no experimental run–by–herbicide treatment interaction for cadillo visible percent control at any evaluation timings; therefore, data were pooled across experimental runs (Table 4). However, herbicide treatment was significant for cadillo visible control at 14 ($P \leq 0.05$; Table 4), 21 ($P \leq 0.01$; Table 4), and 28 DAT ($P \leq 0.01$; Table 4).

Triclopyr applied at 561 and 1,121 g ha^{-1} and 2,4-D at 561, 1,121, and 2,242 g ha^{-1} provided >90% control 14 DAT (Table 4). Triclopyr at 280 g ha^{-1}, AMP at 122 g ha^{-1}, and the high and low rates of imazapyr (IMA) + aminocyclopyrachlor (ACP) + metsulfuron resulted in 86%, 73%, 68%, and 60% control, respectively. All other herbicide treatments provided <60% control. Cadillo control increased with all treatments from 14 to 21 DAT (Table 4). At 21 DAT, the most effective treatments were all rates of triclopyr and 2,4-D, as well as high rate of IMA + ACP + metsulfuron. Both rates of AMP and the high rate of ACP + metsulfuron, and low rate of IMA + ACP + metsulfuron resulted in similar control, ranging from 80% to 89%. All other herbicide treatments provided < 80% control.

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Table 4. Visible estimates of cadillo control 14, 21, and 28 d after treatment (DAT) and dry biomass reduction 28 DAT following POST herbicide treatments under greenhouse conditions near Ona, FL, in 2015.

Herbicide treatments	Rate	DAT[a]			Biomass reduction[a]
	g ae/ai ha^{-1}	14	21	28	
		------------------%------------------			
Triclopyr-ester	280	86 b	97 ab	100 a	91 ab
	561	93 ab	100 a	100 a	93 a
	1,121	96 a	100 a	100 a	92 ab
Aminopyralid	61	55 efg	80 def	91 bcd	82 ef
	122	73 c	87 cde	92 cd	85 def
Metsulfuron	11	51 fgh	73 fgh	87 de	87 a–e
	21	50 fgh	65 hij	83 e	86 c–f
2,4-D amine	561	95 ab	100 a	100 a	90 a–d
	1,121	95 ab	100 a	100 a	91 abc
	2,242	95 ab	100 a	100 a	91 abc
Aminocyclopyrachlor	17	31 j	45 k	70 g	76 g
	35	37 ij	55 jk	75 fg	75 g
	70	56 efg	79 d–g	95 abc	86 b–e
Aminopyralid + metsulfuron	44 + 7	48 fgh	67 hi	80 ef	76 g
	87 + 13	44 hi	59 ij	80ef	75 g
	130 + 20	47 gh	69 gh	93 a–d	83 ef
Aminocyclopyrachlor + metsulfuron	125 + 40	53 efg	77 efg	99 ab	80 fg
	263 + 84	58 ef	85 cde	99 ab	86 c–f
Imazapyr + aminocyclopyrachlor + metsulfuron	288 + 208 + 66	60 de	89 bcd	100 a	87 a–e
	443 + 319 + 102	68 cd	93 abc	100 a	88 a–e

[a]Means within columns followed by the same letter are not significantly different according to Fisher's protected LSD test at $P \leq 0.05$. Means were averaged over experimental run and replicates.

Visible estimates of control for most herbicide treatments continued to increase from 21 to 28 DAT. Triclopyr, 2,4-D, ACP at 70 g ha^{-1}, AMP + metsulfuron at 130 + 20 g ha^{-1}, ACP + metsulfuron, and IMA + ACP + metsulfuron all provided at least 93% control. AMP at 61 and 122 g ha^{-1} also provided effective control (>90% control); however, AMP performance at both rates was significantly lower than the previous herbicide treatments. Metsulfuron-alone treatments provided at least 83% control, whereas the two lower rates of AMP + metsulfuron provided 80% control. The low rate of ACP (17 g ha^{-1}) provided only 70% control, which was not significantly different from ACP at 35 g ha^{-1} with 75% control.

Similar results were reflected in cadillo biomass reduction 28 DAT. There was no experimental run–by–herbicide treatment interaction, but the treatment effect was significant ($P < 0.001$; Table 4). Although the only treatments that provided >90% biomass reduction 28 DAT were those that contained triclopyr and 2,4-D, most herbicide treatments reduced cadillo biomass by at least 80%. The exceptions were the middle and low rates of ACP and AMP + metsulfuron, which provided ≤76% biomass reduction.

Among all herbicide treatments used in the greenhouse study, metsulfuron and IMA are the only ones that are not synthetic auxin herbicides. Metsulfuron and IMA are acetolactate synthase–inhibitor herbicides (Shaner 2014) and therefore would add a different mode of action to the herbicide management program of cadillo, thus reducing the probability of resistance. However, the use of metsulfuron and IMA is limited on account of crop safety. Metsulfuron can be applied to bermudagrass [*Cynodon dactylon* (L.) Pers.] and limpograss [*Hemarthria altissima* (Poir.) Stapf & C.E. Hubbard] pastures in Florida (Abe et al. 2016; Lastinger et al. 2016), but this herbicide cannot be applied to bahiagrass because of crop injury (Bunnell et al. 2003). Furthermore, IMA can only be applied to dormant bahiagrass with <25% green foliage (Anonymous 2018). In summary, the greenhouse results suggested that control of cadillo can be effectively achieved by many different herbicides commonly used in permanent grass pastures and natural areas in Florida.

Field Study

There was no year-by-herbicide treatment interaction for cadillo visible estimates of control at any of the evaluations; therefore, data were pooled across years. However, herbicide treatment was significant for cadillo visible control 15 DAT ($P < 0.01$) and 30 DAT ($P < 0.01$). At 15 DAT, triclopyr + fluroxypyr and triclopyr at 1,121 g ha^{-1} provided at least 85% control. The high rate of 2.4-D provided 78% control, whereas all other treatments provided <70% control (Table 5). Control with ACP and AMP was less than 25% at this rating date.

At 30 DAT, an overall increase in herbicide efficacy was observed for all herbicide treatments (Table 5), as was observed in the greenhouse study (Table 4). Despite the statistical differences, the premix of triclopyr + fluroxypyr, 2,4-D, and triclopyr resulted in at least 94% control. Conversely, AMP at 122 g ha^{-1} provided 71% control, and ACP at both rates resulted in 29% to 48% control.

All herbicide treatments provided 100% control 60 DAT (Table 5), suggesting that all herbicides utilized in this study can effectively control established cadillo plants under field conditions. The extended time period needed for complete control of perennial species with synthetic auxins has been reported in other research. Ferrell et al. (2006), studying permanent grass pastures, suggested a similar trend, as AMP and triclopyr resulted in 72% and 93% control of tropical soda apple at 50 DAT, respectively. Conversely, by 150 DAT control was at least 82%, with no differences between the two treatments. Durham et al. (2016) reported mat lippia [*Phyla nodiflora* (L.) Greene] control with ACP increased over time. ACP and 2.4-D provided 71% and 86% control of 30 DAT, respectively, but by 150 DAT both provided > 90% control. These data collectively imply that AMP and ACP might be slower in

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Table 5. Visible estimates of field populations of cadillo control at 15, 30, and 60 d after treatment (DAT) with POST-applied herbicides near Ona, FL, in 2015 and 2016.

Herbicide treatment	Rate	DAT		
	g ae or ai ha^{-1}	15[a]	30[a]	60[b]
		%	%	%
Triclopyr-ester	561	69 d	96 ab	100
	1,121	85 ab	99 a	100
Aminopyralid	122	38 e	71 c	100
2,4-D amine	1,121	78 c	94 b	100
	2,242	81 bc	98 a	100
Aminocyclopyrachlor	35	12 g	29 e	100
	70	24 f	48 d	100
Triclopyr + fluroxypyr	420 + 140	86 ab	97 ab	100
	841 + 280	90 a	99 a	100

[a]Means within columns followed by the same letter are not significantly different according to Fisher's protected LSD test at $P \leq 0.05$. Means were averaged over years and replicates.
[b]At 60 DAT all treatments provided 100% of visible control; therefore, no statistical analysis was performed.

achieving satisfactory perennial weed control compared to the standard synthetic auxin herbicides triclopyr and 2,4-D.

Awan et al. (2014) reported that 2,4-D-ester at 0.5 kg ha^{-1} provided 98% and 85% control of four- and six-leaf stage cadillo, respectively. In our greenhouse study, 2,4-D provided 100% control regardless of rate, yet we used 1,120 kg ha^{-1} of 2,4-D rate in our field study. Therefore, effective control of cadillo might also be achieved with lower rates of 2,4-D. Among all herbicides tested in the field experiments, AMP and ACP are the only ones with significant soil residual activity (Shaner 2014). AMP appeared to provide cadillo residual control 1 yr after treatment at the location treated in 2015, but not at the location treated in 2016 (data not shown). Therefore, future research assessing the ability of these two and other compounds in providing long-term cadillo residual control in a wider range of soil types and environmental conditions is necessary and would benefit the overall cadillo management program.

Mowing or chopping are the most commonly employed weed control strategies in permanent pastures systems in Florida (Crawford et al. 2011), and we estimate that only 10% of pastures are treated on an annual basis. Although mechanical control methods have the potential to be effective weed control practices when properly adopted, they tend to only suppress or retard regrowth of perennial species, especially when used as the sole management practice. These studies show that cadillo is susceptible to many common herbicides already available for weed control in permanent grass pastures and natural areas in Florida, suggesting that effective control of cadillo can be obtained through traditional herbicide management programs. Therefore, pastures should be scouted and cadillo infestations properly managed before infestation levels affect forage production.

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