Weed Technology 2012 26:554–558

Herbicidal Control of Largeleaf Lantana (*Lantana camara*)

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Largeleaf lantana is a perennial shrub that commonly infests pastures, roadsides, and natural areas. Many experiments have been conducted to manage this weed, but few successful herbicides have been found. Little information is available for the effectiveness of fluroxypyr, aminopyralid, or aminocyclopyrachlor on largeleaf lantana. Experiments were conducted in central Florida on dense, natural infestations of largeleaf lantana. Aminopyralid (0.12 kg ha^{-1}), fluroxypyr (0.56 kg ha^{-1}), and aminocyclopyrachlor (0.2 kg ha^{-1}) were either applied in the fall (approximately 2 mo before frost) or in the fall followed by a spring application. Aminopyralid was ineffective on largeleaf lantana, and neither one nor two applications resulted in $>$ 20% control 1 yr after treatment (YAT). Fluroxypyr applied once in the fall resulted in 12% control at 1 YAT, but two applications resulted in 80% control after 1 yr. The combination of fluroxypyr + aminopyralid, applied twice, resulted in approximately 90% control 1 YAT. A single application of fluroxypyr + aminopyralid failed to provide greater than 20% control. Conversely, aminocyclopyrachlor applied once in the fall provided 98% control of largeleaf at 1 YAT. Where aminocyclopyrachlor was applied twice, largeleaf lantana control was 100%. From these data, largeleaf lantana can be effectively controlled by two applications of fluroxypyr, two applications of fluroxypyr + aminopyralid, or a single application of aminocyclopyrachlor. Individual plant treatments were also investigated using herbicides applied as basal or cut surface applications. At 1 YAT, only triclopyr + aminopyralid provided $>$ 90% control as a basal application. The other herbicide combinations appeared to be effective earlier, but significant regrowth had occurred by 1 YAT. Cut surface applications were similar with triclopyr + aminopyralid and triclopyr + fluroxypyr providing effective control. Neither triclopyr alone nor imazapyr provided effective control for 1 YAT with basal or cut surface applications.

Nomenclature: Aminocyclopyrachlor; aminopyralid; fluroxypyr; imazapyr; triclopyr; largeleaf lantana, *Lantana camara* L. LANCA.
Key words: Basal, broadcast, sequential application.

La *Lantana camara* es un arbusto perene que comúnmente infesta pastizales, orillas de caminos y áreas naturales. Se han realizado muchos experimentos para el manejo de esta maleza, pero se han encontrado pocos herbicidas exitosos. Hay poca información disponible acerca de la efectividad de fluroxypyr, aminopyralid o aminocyclopyrachlor para el control de *L. camara*. Se realizaron experimentos en Florida central en densas infestaciones naturales de esta maleza. Aminopyralid (0.12 kg ha^{-1}), fluroxypyr (0.56 kg ha^{-1}) y aminocyclopyrachlor (0.2 kg ha^{-1}), fueron aplicados ya sea en el otoño (aproximadamente 2 meses antes de la primera helada) o en el otoño seguidos por una aplicación en primavera. Aminopyralid fue inefectivo y ni una ni dos aplicaciones proporcionaron $>$20% de control de *L. camara* un año después del tratamiento (YAT). Fluroxypyr aplicado una vez en el otoño resultó en 12% de control 1 YAT, pero dos aplicaciones proporcionaron 80% de control después de un año. La combinación de fluroxypyr + aminopyralid, aplicada dos veces, resultó en aproximadamente 90% de control 1 YAT. Una sola aplicación de fluroxypyr + aminopyralid falló en proporcionar un control mayor al 20%. Por el contrario, aminocyclopyrachlor aplicado una vez en el otoño proporcionó 98% de control de *L. camara* 1 YAT. Donde se aplicó aminocyclopyrachlor dos veces, el control de esta maleza fue de 100%. A partir de esta información, *L. camara* puede ser controlada efectivamente con dos aplicaciones de fluroxypyr, dos aplicaciones de fluroxypyr + aminopyralid, o una sola aplicación de aminocyclopyrachlor. También se investigaron tratamientos a plantas individuales usando herbicidas aplicados a la base o sobre cortes en la superficie. A 1 YAT, solamente triclopyr + aminopyralid proporcionaron $>$90% de control en aplicaciones a la base. Aparentemente, las otras combinaciones de herbicidas fueron efectivas más temprano, pero al año había ocurrido un rebrote significativo. Aplicaciones a cortes en la superficie tuvieron resultados similares con triclopyr + aminopyralid y triclopyr + fluroxypyr, resultando en un control efectivo. Ni triclopyr solo ni imazapyr proporcionaron control efectivo a 1 YAT con aplicaciones a la base o en los cortes en la superficie.

Largeleaf lantana is a member of the Verbenaceae that is native in the tropical Americas (Ghisalberti 2000) and is commonly found in naturalized populations throughout the southeast United States, from Florida to Texas. Growing as either dense thickets or as individual plants, largeleaf lantana can quickly dominate a landscape by outcompeting native species (Day et al. 2003). This species has been documented to grow best in disturbed sites (Fensham et al. 1994; Thaman 1974). For this reason, largeleaf lantana is reaching epidemic levels in central Florida's abandoned citrus groves that have been renovated to pasture. Since being introduced as a flowering ornamental plant, largeleaf lantana has become one of the top 10 most troublesome weeds in Florida and has been documented in 58 of 67 counties (USDA, NRCS 2012).

The competitive and invasive nature of largeleaf lantana comes from two primary defenses: allelopathy and resistance to herbivory. Allelochemicals produced in the roots and stems have been shown to negatively influence the growth and competitive ability of surrounding species and eventually to

DOI: 10.1614/WT-D-11-00170.1

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decrease biodiversity (Achhireddy and Singh 1984; Achhireddy et al. 1985; Foy and Inderjit 2001). This allows monotypic stands to develop readily, and once established, those stands are highly persistent in the environment. Persistence of largeleaf lantana is due to many factors, but one, in particular, is its resistance to herbivory because of toxin accumulation in the leaves (Ghisalberti 2000). This, coupled with its tolerance for continual defoliation for 1 to 2 yr (Broughton 1999; Winder 1980), has greatly hampered the development of a biological control program (Baars 2003; Broughton 2000).

Largeleaf lantana is considered one of the 10 most toxic weeds in the world (Sharma et al. 1988). Ingesting approximately 3 mg of dry leaves per kilogram of body weight is a toxic dose for ruminant animals (Ghisaberti 2000). Foraging of largeleaf lantana by large animals can result in either acute (death within 12 to 24 h) or chronic poisoning, with the common symptoms of skin cracking and peeling (Knight and Walter 2001). Regardless of quantity eaten, cattle that show symptoms of largeleaf lantana toxicity rarely recover and resume productive gains (Seawright 1963). The cattle industry is an important component of southeast agriculture, and it is critical to develop economically viable and sustainable control methods to prevent losses from largeleaf lantana.

Mechanical control has been difficult to achieve. Being a woody perennial, the plants must be cut above the soil surface and the root system removed with additional implements to prevent resprouting (Graaf 1986). Because of the expense, labor, and soil disturbance caused by these mechanical methods, herbicides have been the preferred method of control. However, herbicidal control of largeleaf lantana has been variable and difficult to achieve. The variability in control has been attributed to the fact that more than 650 cultivars of largeleaf lantana are known (Graaf 1986). Regardless of cultivar, most researchers have examined the efficacy of 2,4-D, glyphosate, and triclopyr. Glyphosate, although quite consistent (Erasmus and Clayton 1992; Graaff 1986; Toth and Smith 1984), is undesirable because of the nontarget damage that is typical of its nonselective activity. In Florida, two commonly used pasture herbicides are 2,4-D and triclopyr. This is troubling because 2,4-D has frequently been shown to be inconsistent (Bartholomew and Anderson 1978; Singh et al. 1997), whereas triclopyr has little or no activity on largeleaf lantana (Graaff 1986; Toth and Smith 1984). Therefore, it is important to test other herbicides that would be safe on pasture grasses to determine whether they possess activity on largeleaf lantana. Aminopyralid is an herbicide with many structural and physical similarities to picloram (Fast et al. 2010). Considering the broad-spectrum activity of picloram on woody brush, it is necessary to determine whether aminopyralid would likewise be effective against largeleaf lantana. Additionally, aminocyclopyrachlor is a new auxin-mimic herbicide that is being tested for use on woody brush (Turner et al. 2010). It is currently unknown whether aminocyclopyrachlor has activity against largeleaf lantana. The objectives of this research were (1) to determine whether foliar-applied herbicides can effectively control largeleaf lantana, and (2) to determine whether herbicides applied as a basal treatment to standing plants or to cut surfaces will result in plant death.

Table 1. Herbicide formulations and rates for lantana control experiments.

Common name	Trade name	Formulation	Rate	Manufacturer
Broadcast applications				
Aminopyralid	Milestone	240 g L^{-1}	0.12 kg ha^{-1}	Dow AgroSciences Indianapolis, IN
Aminopyralid + 2,4-D	GrazonNext	40 g L^{-1} aminopyralid + 320 g L^{-1} 2,4-D	0.12 + 1 kg ha^{-1}	Dow AgroSciences Indianapolis, IN
Fluroxypyr	Vista	180 g L^{-1}	0.56 kg ha^{-1}	Dow AgroSciences Indianapolis, IN
Aminopyralid + fluroxypyr	Milestone + Vista	240 g L^{-1} aminopyralid + 180 g L^{-1} fluroxypyr	0.12 + 0.56 kg ha^{-1}	Dow AgroSciences Indianapolis, IN
Aminocyclopyrachlor	TBA	50% ai, dry formulation	0.21 kg ha^{-1}	DuPont, Wilmington, DE
Basal and cut surface applications				
Triclopyr ester	Remedy Ultra	480 g L^{-1}	20% solution	Dow AgroSciences Indianapolis, IN
Triclopyr ester + fluroxypyr	Pasturegard	180 g L^{-1} triclopyr + 60 g L^{-1} fluroxypyr	50% solution	Dow AgroSciences Indianapolis, IN
Triclopyr ester + aminopyralid	Remedy Ultra + Milestone	480 g L^{-1} triclopyr + 240 g L^{-1} aminopyralid	20% triclopyr + 1% aminopyralid	Dow AgroSciences Indianapolis, IN
Imazapyr	Stalker	240 g L^{-1}	3% solution	BASF, Research Triangle Park, NC

https://doi.org/10.1614/WT-D-11-00170.1 Published online by Cambridge University Press

Table 2. Control of lantana with foliar broadcast herbicides. Applications were made in Fall 2007 and Spring 2008.[a,b]

Herbicide	Timing	Rate	2 MAT	6 MAT	12 MAT
		kg ha^{-1}	% control		
Aminopyralid	Fall	0.12	8 f	6 e	0 c
Aminopyralid	Fall + spring	0.12	36 e	25 d	16 bc
Aminopyralid + 2,4-D	Fall	0.12 + 1	23 ef	0 e	6 bc
Aminopyralid + 2,4-D	Fall + spring	0.12 + 1	43 de	60 c	0 c
Fluroxypyr	Fall	0.56	68 bc	65 bc	12 bc
Fluroxypyr	Fall + spring	0.56	86 ab	80 ab	77 a
Fluroxypyr + aminopyralid	Fall	0.56 + 0.12	63 cd	53 c	20 b
Fluroxypyr + aminopyralid	Fall + spring	0.56 + 0.12	97 a	95 a	90 a

[a] MAT, months after treatment; indicates number of months after the last herbicide application, whether it occurred in the fall or the spring.

[b] Means followed by similar letters do not differ at P = 0.05 level of significance.

Materials and Methods

Experiments were initiated in September 2007 in Pasco County, FL (28°21′N, 82°11′W), and again in September 2009 in Lake County (28°48′N, 81°52′W) and DeSoto County (27°12′N, 81°52′W), FL. All locations were livestock pastures with a naturally occurring largeleaf lantana infestation of approximately 1 plant 3 m^{-2}.

Herbicides were applied using an all-terrain vehicle–mounted sprayer calibrated to deliver 230 L ha^{-1}. Plots were 8 m wide by 16 m long with a 5-m, nontreated buffer maintained between each set of sprayed plots. The nontreated buffer was used to allow accurate evaluation of largeleaf lantana control to account for the variable density across the experimental area. Nonionic surfactant was added to each herbicide treatment at 0.25% v/v. The experimental design was a two by five factorial (two application timings and five herbicides) with four replications.

Foliar-broadcast application of herbicides was initiated in the fall, approximately 2 mo before the first frost. Largeleaf lantana plants were not mowed before foliar application. Herbicide treatments are listed in Table 1. Each of these herbicides was applied once in the fall, or sequentially as a fall application followed by an additional application in the spring (approximately 6 mo later). In 2009, single and sequential applications of aminocyclopyrachlor (0.21 kg ha^{-1}) were included.

In a separate trial at the same locations in 2007 and 2009, herbicides mixed with basal oil were applied to individual plants (Table 1). Herbicides were applied at a volume sufficient to cover the base of the plant and the surrounding stems. Additionally, another set of plants was clipped with a rotary mower to a height of 10 cm and the herbicide–oil mixture was applied immediately to the cut surfaces. For these experiments, each treated plant was considered a replication, and 10 replications per treatment were used. Aminocyclopyrachlor was not incorporated into this study because an oil-miscible formulation was not available.

Visual estimates of control were recorded on a scale of 0 to 100, where 0 is no control and 100 is complete control. Evaluations were conducted at 2, 6, and 12 mo after treatment (MAT). All data were tested for main effects and interactions using ANOVA. Treatment means were separated using Fisher's Protected LSD test at P = 0.05.

Results and Discussion

For the 2007 broadcast experiment, a herbicide by application timing interaction was observed, and data are presented accordingly. For this location, it was observed that neither aminopyralid nor aminopyralid + 2,4-D provided acceptable control at 12 MAT (Table 2). At 2 and 6 MAT, the sequential treatments improved control by 20 to 60%. However, both the single and sequential treatments provided

Table 3. Control of lantana with foliar broadcast herbicides. Applications were made in Fall 2009 and Spring 2010 at two locations.[a,b]

Herbicide	Timing	Rate	2 MAT	6 MAT	12 MAT
		kg ha^{-1}	% control		
Aminopyralid	Fall	0.12	10 d	0 c	0 e
Aminopyralid	Fall + spring	0.12	15 c	12 c	20 d
Aminopyralid + 2,4-D	Fall	0.12 + 1	5 d	5 c	9 de
Aminopyralid + 2,4-D	Fall + spring	0.12 + 1	70 b	65 b	35 c
Fluroxypyr	Fall	0.56	72 b	12 c	12 de
Fluroxypyr	Fall + spring	0.56	92 a	93 a	80 b
Fluroxypyr + aminopyralid	Fall	0.56 + 0.12	92 a	5 c	10 de
Fluroxypyr + aminopyralid	Fall + spring	0.56 + 0.12	95 a	97 a	93 a
Aminocyclopyrachlor	Fall	0.21	47 c	96 a	96 a
Aminocyclopyrachlor	Fall + spring	0.21	98 a	99 a	100 a

[a] MAT, months after treatment; indicates number of months after the last herbicide application, whether it occurred in the fall or the spring.

[b] Means followed by similar letters do not differ at P = 0.05 level of significance.

https://doi.org/10.1614/WT-D-11-00170.1 Published online by Cambridge University Press

Table 4. Efficacy of herbicides applied to individual lantana plants as a cut-surface or basal application.[a,b]

Herbicide	Rate	Cut-surface		Basal	
		6 MAT	12 MAT	6 MAT	12 MAT
	% v/v	% control			
Triclopyr	20	53 b	20 c	50 c	27 b
Triclopyr + fluroxypyr	50	95 a	95 a	82 b	80 a
Triclopyr + aminopyralid	20 + 1	90 a	95 a	50c	95 a
Imazapyr	3%	99 a	70 b	99 a	30 b

[a] MAT, months after treatment; indicates number of months after the last herbicide application, whether it occurred in the fall or the spring.

[b] Means followed by similar letters do not differ at $P = 0.05$ level of significance.

less than 16% control at 12 MAT, and no differences were observed. The application of fluroxypyr once in the fall resulted in control that was similar to the aminopyralid treatments. Although single fluroxypyr and fluroxypyr + aminopyralid applications provided higher control initially, control did not differ from the single or sequential aminopyralid or aminopyralid + 2,4-D treatments by 12 MAT. Conversely, additional spring application of fluroxypyr or fluroxypyr + aminopyralid dramatically improved control over all other treatments. Fluroxypyr and fluroxypyr + aminopyralid provided 77 and 90% control, respectively, at 12 MAT. No reports could be found that have documented the efficacy of aminopyralid or the effect of sequential applications on largeleaf lantana control. Many reports have discussed the efficacy of 2,4-D (Graaff 1986; Singh et al. 1997), but, at the rates tested in this trial, the low level of control was expected.

For experiments conducted in 2009, two locations were used, and no treatment by location interaction was observed, so data were pooled across locations. However, a treatment by timing interaction was observed, and those data are presented accordingly. The results in 2009 were similar to those in 2007. Aminopyralid (single and sequential), aminopyralid + 2,4-D (single and sequential), fluroxypyr (single), fluroxypyr + aminopyralid (single) all provided less than 35% control at 12 MAT (Table 3). Conversely, sequential applications of fluroxypyr and fluroxypyr + aminopyralid provided 80 and 93% control, respectively, at 12 MAT. From these data, it was observed that two applications of fluroxypyr are necessary if control is to approach acceptable levels. The addition of aminopyralid to fluroxypyr numerically improved control on both occasions, but was only statistically significant in 2009 at 12 MAT.

Although fluroxypyr is effective, there are limitations to this program. First, two applications in close succession must be conducted. One application was shown to fail, whereas a fall application followed by spring application was consistently successful. However, it is unknown if control from the sequential treatments will be adversely affected if the second application is delayed until summer or later. Secondly, the price of two applications of fluroxypyr + aminopyralid may likely be inhibitory for most ranchers. Currently, this treatment could cost as much as \$100 ha^{-1}, not considering the cost of application (Ferrell and MacDonald 2010).

The efficacy of aminocyclopyrachlor was also explored in these field experiments. It was observed that both single and sequential applications of aminocyclopyrachlor at rates of 0.21 kg ha^{-1} provided 96% or greater control at 12 MAT. Previous research has shown this same level of control with other herbicides (Graaff 1986; Toth and Smith 1984), generally with glyphosate, which cannot be applied broadcast to pastures because of unacceptable levels of grass injury. Conversely, aminocyclopyrachlor has been shown to be safe on numerous grass species (Enloe et al. 2010; Rhodes 2010). Although hundreds of lantana cultivars have been described and implicated as a reason for inconsistent herbicide control (Graaff 1986), the efficacy of aminocyclopyrachlor was striking. We cannot, from these data, draw broad conclusions about the efficacy of aminocyclopyrachlor on all lantana biotypes. However, aminocyclopyrachlor was greatly superior to all other treatments tested, and additional research on geographically distinct populations is warranted.

It is important to follow a broadcast application with a spot-treatment of herbicides to remove any plants that escape treatment. Because many foliar herbicides used for spot-treatment have been shown to be inconsistent (Graaff 1986; Singh et al. 1997; Toth and Smith 1984), we attempted to determine whether alternative application techniques could be effective. To do this, experiments were conducted to evaluate the efficacy of herbicides diluted in oil carrier and applied directly to largeleaf lantana stems, or freshly cut stem surfaces. There was no treatment by location interaction for individual plant treatment experiments conducted in 2007 and 2009; therefore, data were pooled across locations. Imazapyr was observed to provide excellent control at 6 MAT but declined to 30% for basal applications and 70% for cut surfaces at 12 MAT (Table 4). Previous research has shown excellent control with imazapyr (Graaff 1986). Although plants in the current experiments were defoliated and stunted by the application, full regrowth was observed in many of the treated plants. Control with triclopyr alone was poor. Less than 27% control was observed at 12 MAT when triclopyr was applied to stems or cut surfaces. Although triclopyr was applied at rates much higher than in previous reports, the level of control was similar (Graaff 1986). At 12 MAT, less than 27% control was observed when triclopyr was applied to stems or cut surfaces. The addition of fluroxypyr or aminopyralid with triclopyr greatly improved control over triclopyr alone, and no differences were observed between these combinations. Therefore, if basal or cut surface applications are required, the addition of fluroxypyr or aminopyralid would be necessary to maximize control. Basal applications on a species such as largeleaf lantana are difficult. This is a multistemmed species and applying proper coverage on all the stems is quite difficult and requires large amounts of spray solution. Considering that high herbicide concentrations are required for this application procedure, the excessive cost of this application would likely be inhibitory. Application to the cut surfaces is also challenging. Simply finding all the target individuals after a mowing operation has been performed can be quite difficult, and it is likely many of the plants could be missed. Based on this, additional research to determine efficacious herbicide mixtures for foliar spot-applications on largeleaf lantana is necessary.

Largeleaf lantana will likely continue to be a troublesome species across Florida and many other parts of the world. However, fluroxypyr + aminopyralid combinations and aminocyclopyrachlor will contribute to the management of this invasive plant. Additional research is warranted to determine whether geographically distinct populations will respond to these herbicides in the manner reported here. Additionally, aminocyclopyrachlor was found to provide nearly 100% control with one application of 0.21 kg ha^{-1}. It may be possible that this rate can be reduced while still achieving acceptable control. Continued research is needed to describe largeleaf lantana response to reduced rates of aminocyclopyrachlor.

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Received November 22, 2011, and approved February 17, 2012.