Herbicide Treatment and Application Method Influence Root Sprouting in Chinese Tallowtree (*Triadica sebifera*)

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Chinese tallowtree is an invasive tree found throughout the southeastern United States and in California. Its negative effects can be seen in numerous natural and managed ecosystems, including bottomland hardwood forests, pastures, pine plantations, and along lakes, ponds, streams, and rivers. Despite its troublesome presence for many decades, relatively few effective control strategies are available. Root sprouting following management efforts is a major impediment to successful control. Studies were conducted in Alabama and Louisiana at three locations to test several herbicides for cut stump, basal bark, and foliar individual plant treatment (IPT) methods. Herbicide treatments included triclopyr amine and ester formulations, imazamox, aminopyralid, aminocyclopyrachlor, and fluroxypyr. Data were collected just before leaf senescence at one and two growing seasons after treatment and included Chinese tallowtree foliar cover, number of stump or root collar sprouts, and number of sprouts originating from lateral roots within a 1-m radius of each tree. For the cut stump and basal bark studies, most herbicide treatments prevented sprouting from the stump or root collar region better than they did from the lateral roots. Aminopyralid reduced total sprouting better than all other treatments in the cut stump study. The high rates of aminocyclopyrachlor and fluroxypyr resulted in the highest mortality in the basal bark study. Aminocyclopyrachlor reduced total sprouting better than all other herbicides in the foliar treatment study. Triclopyr amine and ester formulations, which are commercial standards, did not consistently control Chinese tallowtree across these IPT studies. These studies provide some promising treatments to increase the number of effective tools that can be used to manage Chinese tallowtree. Additional research is needed to address the prolific nature of lateral root sprouting following any of these treatment methods.

Nomenclature: Aminocyclopyrachlor; aminopyralid; fluroxypyr; imazamox; triclopyr; Chinese tallowtree, *Triadica sebifera* (L.) Small.

Key words: Basal bark, cut stump, foliar treatment, individual plant treatment, invasive plant control.

Chinese tallowtree [*Triadica sebifera* (L.) Small], is an aggressive tree from southeast Asia capable of invading a wide variety of habitat types, including coastal prairies, bottomland hardwood forests, pastures, pine plantations, and areas along lakes, ponds, streams, and rivers (Gan et al. 2009; Meyer 2005). Spread primarily through avian dispersal (Renne et al. 2002), Chinese tallowtree populations have increased rapidly during the past two decades. In Louisiana, Chinese tallowtree has increased more than 500% between 1991 and 2005, and it ranks as the fifth most-common tree (Oswalt 2010). Similar explosive increases in local populations are occurring across the Gulf Coast, extending as far north as central Alabama and southern Arkansas (EDDMapS 2014). Furthermore, models predict that the range of Chinese tallowtree could expand as far north as the Ohio River (Pattison and Mack 2008).

The rapid spread and the ability of Chinese tallowtree to form monospecific stands are of concern to managers of natural areas and managed forests and farms. Chinese tallowtree is reported to displace native species (Bruce et al. 1997), is potentially toxic to livestock (Russel et al. 1969), affects nutrient cycling (Cameron et al. 1989), and is having an increasing effect on production forestry (Wang et al. 2012). In addition to rapid growth, the tremendous reproductive pressure of Chinese tallowtree contributes to invasion success. Mature trees can produce 100,000 seeds yr^{-1} or more (Renne and Gauthreaux 2000), and saplings

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Management Implications

Chinese tallowtree is an increasing problem across the southeastern United States. However, there is little published research examining effective control methods. We compared several newer herbicides with the commercial standards triclopyr ester and triclopyr amine for foliar, cut stump, and basal bark individual plant treatment (IPT) methods in natural areas. We examined both root collar and lateral root sprouting response to herbicide treatment, which is rarely done in invasive plant studies. We found that aminocyclopyrachlor, aminopyralid, fluroxypyr, and imazamox all controlled Chinese tallowtree similar to, or better than, triclopyr in specific IPT studies. Aminocyclopyrachlor resulted in greater mortality of Chinese tallowtree than triclopyr did in foliar and basal bark studies, whereas aminopyralid was more effective than triclopyr in cut stump studies. Fluroxypyr resulted in greater mortality than triclopyr in cut stump and basal bark studies but not in foliar studies. This research highlights the strong need to continue to evaluate new tools for invasive plant control and the need to continuously collect better data on invasive plant responses to treatment.

can begin producing seed within 3 yr (Miller et al. 2010). Spread can also occur vegetatively through vigorous stump sprouting and root suckering (Meyer 2005).

Despite the phenomenal spread and negative effects of Chinese tallowtree, there is not a single peer-reviewed, published study, to our knowledge, evaluating herbicide treatments and application methods for control. Most recommendations of Chinese tallowtree control refer back to conference abstracts and proceedings, the grey literature, or brief mentions of treatment methods (Jubinsky 1993; Jubinsky and Anderson 1996; Kline and Duquesnel 1996; Langeland 2006; Miller et al. 2010; Randall and Marinelli 1996, Yeiser et al. 2012). These discussions largely point to the use of triclopyr ester formulations for basal bark or foliar treatment, triclopyr amine formulations for cut stump and foliar treatment, and imazapyr or picloram for foliar and injection treatments. Although follow-up treatments to address coppicing or lateral root sprouting is almost always recommended within these sources, there are no published data, to our knowledge, to inform managers on the initial effectiveness of the different treatment approaches. Furthermore, the extent of sprouting that may occur following treatment, especially from lateral roots, has never, to our knowledge, been examined. This is somewhat surprising because Chinese tallowtree is a prolific stump and lateral root sprouter, with vigorous, rapid regrowth following cutting. In biomass production studies, Scheld and Cowles (1981) found that Chinese tallowtree seedlings planted at high density produced up to 11.2 t ha^{-1} (5 tons ac^{-1}) of dry biomass at the end of the second growing season, whereas coppiced plots produced 15.7 t ha^{-1} 7 t ac^{-1}. This regrowth potential clearly suggests that stronger quantitative assessments of Chinese tallowtree treatment efficacy would be useful for better-designed management programs.

In addition to a lack of published studies, most of the control recommendations that are available date back almost 20 yr. However, since then, there have been several new herbicide chemistries registered for use in specific noncrop, aquatic, natural areas, forests, or pasture situations where Chinese tallowtree is a serious problem. These include aminocyclopyrachlor, aminopyralid, fluroxypyr, and imazamox. These chemistries have recently been shown to have considerable utility in weedy and invasive plant management (Enloe et al. 2008, 2012; Fast et al. 2009; Ferrell et al. 2009; Minogue et al. 2011), and they warrant testing on this woody species. Therefore, our objective was to evaluate the response of Chinese tallowtree to several new herbicides applied via multiple individual plant treatment (IPT) techniques, including cut stump, foliar, and basal bark treatment methods. We compared these methods against standard recommendations with triclopyr amine or ester formulations, depending on the IPT method used, and we evaluated both root collar and lateral root sprouting.

Materials and Methods

Cut stump, basal bark, and foliar-applied IPT studies were each conducted at three locations near Montgomery, AL; Wetumpka, AL; and Pineville, LA, from December 2010 through October 2013. The Wetumpka, AL, site was a 6-yr-old, 10 ha (25 ac) Conservation Reserve Program (CRP), bottomland hardwood site composed of six species, including white oak (*Quercus alba* L.), swamp white oak (*Quercus bicolor* Willd.), Nuttall oak (*Quercus texana* Buckley), cherrybark oak (*Quercus pagoda* Raf.), willow oak (*Quercus phellos* L.), and Shumard's oak (*Quercus shumardii* Buckley). Chinese tallowtree rapidly invaded the area after planting, and individual trees of 4 to 6 m (13 to 20 ft) in height occurred throughout the planted area. Soils were predominantly Congaree fine sandy loam with some areas of Chewacla silt loam. The Montgomery, AL, site was a 5 ha bahiagrass (*Paspalum notatum* Fluegg) pasture containing several 0.5-ha Chinese tallowtree hammocks, approximately 20 yr old. Previous efforts to control them with mowing had resulted in a mix of multistemmed and single-stemmed trees 6 to 10 m tall. Soils were a Kipling very fine sandy loam. The Pineville, LA, site was also an invaded bahiagrass pasture with 6- to 10-m individual trees found throughout the site. Soils were a Glenmora silt loam.

For each IPT study, a completely randomized experimental design (CRD) was used with individual Chinese tallowtree trees as experimental units. Within each study, each treatment was replicated on 20 individual trees, with a target spacing of at least 10 feet between trees, although this was not possible in all cases. Herbicides treatments included aminocyclopyrachlor (DuPont, Wilmington, DE 19898), aminopyralid (Milestone VM, Dow AgroSciences,

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Table 1. Herbicide formulations and rates used in each study.

Herbicide	Formulation	Rates		
		Cut stump	Basal bark	Foliar
	% ai or g L^{-1}		g L^{-1}	
Aminocyclopyrachlor	50%	—	—	1.5
	120 g L^{-1}	—	12, 24	—
Aminopyralid	240 g L^{-1}	24	—	0.6
Fluroxypyr	336 g L^{-1}	34, 84	34, 68	1.5
Imazamox	120 g L^{-1}	30, 60	—	2.4
Triclopyr amine	360 g L^{-1}	90	—	7.2
Triclopyr ester	480 g L^{-1}	—	48, 96	—

Indianapolis, IN 46268), fluroxypyr (Vista XRT, Dow AgroSciences, Indianapolis, IN 46268), imazamox (Clearcast, BASF, Research Triangle Park, NC 27709), triclopyr amine (Garlon 3A, Dow AgroSciences), and triclopyr ester (Garlon 4, Dow AgroSciences). Formulation information and rates for each herbicide treatment within each IPT study are given in Table 1. Appropriate untreated controls were also included for each IPT study. For the cut stump and foliar studies, controls were cut, but no herbicide was applied. For the basal bark study, untreated controls were left alone throughout the duration of the study.

For cut stump and foliar studies, all herbicides were mixed with water and a nonionic surfactant (Timberland 90, Loveland Products, Loveland, CO 80538) at 0.5% v/v. For the basal bark study, all herbicides were mixed with an oil carrier (Bark Oil Blue, UAP Distribution, Inc., Greeley, CO 80634).

The cut stump and basal bark treatment applications occurred during the week of December 8, 2010, through December 13, 2010, after leaf drop. Before the initiation of treatments, the root collar diameter of each tree was measured with wooden calipers and recorded. For cut stump treatments, individual trees were cut with a chainsaw (Husqvarna 123HD60, Husqvarna, Charlotte, NC 28269), leaving a flat, 2.5-cm (1-in) (height from the soil surface) stump. Any accumulated sawdust or other debris was quickly removed, and herbicide treatments were applied within 30 s of cutting. Treatments were applied with a 1.5-L hand pump pressurized sprayer with a single adjustable cone nozzle. Treatments were applied in a 5-cm band around the perimeter of each stump to completely cover the cambium. The amount of herbicide applied varied with the size of each stump. However, the average total amount of herbicide solution used to treat all 20 stumps was 252 ml (8.5 oz) or 12.6 ml per stump. The average root collar diameter (RCD) of individual stumps was 13.7 cm for a total solution volume of 0.9 ml cm^{-1} (0.08 oz in^{-1}) of RCD.

Basal bark herbicide treatments were applied to the bark in a 30- to 36-cm band at the base of each stem. Treatments were applied to all stems if experimental units were multistemmed trees. The amount of herbicide applied varied with the RCD and the number of stems of each experimental unit. However, the average total amount of herbicide solution used to treat all 20 stumps at each site was 885 ml or 44 ml per experimental unit. The average RCD of individual stumps was 13.5 cm for a total solution volume of 3.27 ml cm^{-1} of RCD.

Foliar treatments were applied in a two-step method. First, all experimental units were cut with a chainsaw to a stump height of 2.5 cm in January 2011. New sprouts initiated in the spring of 2011 from the root collar and lateral roots and were allowed to grow for 6 mo until mid-June 2011; at which time, the herbicide treatments were applied. Herbicides were applied to the foliage of all new growth with a backpack sprayer (STIHL SG20, Virginia Beach, VA 23452) equipped with a single adjustable cone nozzle at an application volume of 468 L ha^{-1} (50 gal ac^{-1}). The average total amount of herbicide solution used to treat the foliage of all 20 experimental units at each site was 7 L (18.5 gal) or 354 ml per experimental unit. Chinese tallowtree height averaged 1.47 m at the time of herbicide treatment, and each experimental unit averaged approximately 19 stems. The extremely dense foliage on such a high number of stems per experimental unit, coupled with the target application volume 468 L ha^{-1} resulted in the relatively large application volume required per individual.

Data were collected at each location in October 2012 at the end of the first growing season after treatment (GSAT) and in late August through early October 2013 at the end of the second GSAT. Total number of new sprouts originating from the stump, the root collar area within 2.5 cm of the stump (hereafter referred to as *root collar sprouts*), and all new sprouts initiating from lateral roots within a 1-m radius of each stump were counted. Additionally, the height of the tallest sprout for both root collar sprouts and lateral root sprouts was measured. Sprouts were separated by origination point to better quantify the effect of the treatments. The origin of sprouts from lateral roots within

Table 2. Chinese tallowtree mean sprouting response to cut stump herbicide treatment and growing season after treatment (GSAT).

Herbicide	Rate	Root collar sprouts[a]		Lateral root sprouts[b,c]		Total sprouts[c]	
		No.	ht	No.	ht	No.	ht
	g L^{-1}		cm		cm		cm
Aminopyralid	24	0.03	1.0	1.3 a	33 a	1.3 a	35 a
Fluroxypyr	34	0.02	1.0	4.6 bc	135 cd	4.7 bc	136 c
	84	0.00	0.0	2.6 ab	73 b	2.6 b	73 b
Imazamox	30	0.34	14.0	7.6 c	86 bc	7.9 cd	100 bc
	60	0.69	10.0	8.6 c	90 bc	9.3 d	99 bc
Triclopyr	90	3.42	106	10.5 c	182 d	13.9 de	288 d
Untreated	—	18.24	281	3.7 b	122 cd	22.0 e	403 d
Season							
One GSAT	—	3.93	44	7.0 A	75 A	11.0 A	120 A
Two GSAT	—	2.56	73	4.1 B	131 B	6.7 B	204 B

[a] Root collar sprouts include all new sprouts originating from the stump and root collar area within 2.5 cm of the stump base.

[b] Lateral root sprouts include all new sprouts within a 1-m radius of the root collar (3.14 m^2 area around each tree).

[c] Treatment means within columns followed by either the same uppercase or lowercase letter are not significantly different at $P = 0.05$.

the 1-m radius was generally easy to discern because lateral roots were exposed or just below the soil surface for that distance. Chinese tallowtree seedlings were hand pulled around each stump at the first sample date to prevent subsequent confusion with lateral root sprouts. Seedlings were generally easy to hand pull, whereas sprouts from lateral roots could not be readily hand pulled.

Data Analyses. ANOVA was performed as a mixed model, with locations considered a random effect, and sample date (one or two GSAT) nested within treatment as a repeated measure. Variables for averaged sum of heights and averaged number of sprouts were transformed using the natural log function to reduce the variance heterogeneity observed in a preliminary analysis. Analysis of the percentage of foliar cover was performed using the arcsin square root of the proportional cover transformation. Statistical analyses were performed on average rootstock foliar cover, average sprout counts, and the heights of lateral or lateral and root collar sprouts using PROC MIXED. Root collar sprout counts and heights were not analyzed separately for the cut stump or basal bark studies because most of those data were zeroes across herbicide treatments. This was clearly observed in the similarity of the lateral sprout data to the total sprout (root collar sprouts plus lateral sprouts) data.

PROC GLIMMIX was used for the analysis of mortality, assuming a binomial distribution for the total kill variable, and location included as a random effect. This model fit well with no indication of overdispersion, but it was necessary to remove the untreated control from the analysis to achieve convergence. This was due to no rootstocks having died on the untreated control at any location. The untreated control was not included in the statistical analysis of mortality but provides a valuable baseline and objective evidence that mortality did not occur from factors other than herbicide treatments. Because the concern here was to identify the best treatments (as opposed to comparing poorer treatments with each other), a Fisher's protected LSD test was used to compare means. Means were declared significantly different based at the 5% level of significance but only if the overall effect was significant.

Results

Cut Stump Study. In general, most herbicide treatments strongly inhibited new sprout production from the root collar (Table 2). Where root collar sprouting was zero, treated stumps generally appeared completely dead and were in various stages of decomposition. The exception was stumps treated with triclopyr, which averaged 3.4 sprouts per root collar. However, triclopyr still reduced root collar sprouting by 81% compared with the untreated control.

Lateral root sprout production, total sprout production, and maximum sprout heights for both lateral and root collar sprouts were strongly influenced by herbicide treatment and GSAT ($P < 0.001$ for both main effects, for all dependent variables tested). The untreated control averaged 3.7 new lateral root sprouts and was similar to both fluroxypyr treatments (Table 2). Aminopyralid reduced lateral root sprouts compared with all treatments except the high rate of fluroxypyr. Both rates of imazamox and triclopyr more than doubled lateral root sprouting compared with the untreated control.

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Table 3. Chinese tallowtree rootstock mortality at two growing seasons after treatment for cut stump, basal bark, and foliar applied studies. Criteria used to calculate mortality was zero new sprouts from both the root collar and the lateral roots and zero percentage of foliar cover.

Herbicide	Rate	Cut stump	Basal bark	Foliar
	$g\ L^{-1}$	Probability of rootstock mortality[a]		
Aminocyclopyrachlor	1.5	—	—	0.67 a
	12	—	0.59 b	—
	24	—	0.86 a	—
Aminopyralid	0.6	—	—	0.22 bc
	24	0.68 a	—	—
Fluroxypyr	1.5	—	—	0.25 abc
	34	0.25 cd	0.59 b	—
	84	0.51ab	0.72 ab	—
Imazamox	2.4	—	—	0.56 ab
	30	0.30 bc	—	—
	60	0.22 cd	—	—
Triclopyr amine	7.2	—	—	0.11 c
	90	0.11 d	—	—
Triclopyr ester	48	—	0.26 c	—
	96	—	0.26 c	—
Untreated	—	0.0	0.0	0.0

[a] Treatment means within columns followed by the same letter are not significantly different at P = 0.05.

Herbicide treatment effects on total sprout production were somewhat similar to lateral root sprout production because lateral sprouts composed most of all sprouts counted, with the exception of the untreated control (Table 2). Aminopyralid reduced total sprouting by 95% compared with the untreated control and was different from all other herbicide treatments. Fluroxypyr reduced total sprouting by 79 and 88% at the low and high rates, respectively. Imazamox reduced total sprouting by 61 and 64% at the low and high rates, respectively, and triclopyr reduced total sprouting by 37%.

Both lateral root sprout and total sprout number decreased from the end of the first to the end of the second growing season after treatment (Table 2). This was likely due to self-thinning of the root collar sprouts in the untreated controls.

Although a decrease in sprout number may be indicative of an herbicide effect, sprout growth should also be a strong indicator of whether or not plants were able to overcome herbicide effects following treatment. For root collar sprouts, the untreated control averaged 281 cm for maximum sprout height following cutting (Table 2). Treatment with triclopyr resulted in 106 cm for maximum sprout height from root collar sprouts following cutting. All other herbicide treatments resulted in maximum root collar sprout heights of 14 cm or less.

Maximum height of lateral root sprouts varied among herbicide treatments. Aminopyralid resulted in a maximum lateral root sprout height of 33 cm, which was shorter than all other treatments. Maximum lateral root sprout height for the high rate of fluroxypyr was similar to both rates of imazamox but lower than all other treatments. Imazamox and the low rate of fluroxypyr were similar to the untreated control. Triclopyr resulted in the numerically tallest maximum sprout height (182 cm) and was similar to the untreated control.

Across treatments, maximum height of root collar sprouts, lateral sprouts, and total sprouts almost doubled from the end of one GSAT to two GSAT. This suggests that although sprout number decreased between the first and second GSAT, remaining sprouts were growing vigorously and had overcome herbicide treatment.

Chinese tallowtree rootstock mortality, defined for the cut stump study as a rootstock with zero new root collar or lateral sprouts within a 1-m radius, significantly differed among herbicide treatments (P = 0.002) but did not differ between GSAT (P = 0.16). Aminopyralid resulted in the highest mortality rate at two GSAT (68%), and this was greater than all other herbicide treatments except the high-rate fluroxypyr treatment (Table 3). All other treatments resulted in 30% or less mortality at two GSAT.

Basal Bark Study. Foliar cover from basal bark–treated stems varied among treatments (P < 0.001) but was not different between one and two GSAT (P = 0.85). All herbicide treatments reduced foliar cover compared with the untreated control. Aminocyclopyrachlor and fluroxypyr at the high rates reduced foliar cover to zero and were

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Table 4. Chinese tallowtree sprouting response to basal bark herbicide treatment and growing season after treatment (GSAT).

Herbicide	Rate	Foliar cover[c]	Root sprouts[a]		Lateral root sprouts[b,c]		Total sprouts[c]	
			No.	ht	No.	ht	No.	ht
	g L^{-1}	%		cm		cm		cm
Aminocyclopyrachlor	12	3 ab	0.3	2	1.8 b	43 a	2.1 b	46 a
	24	0 a	0.0	1	0.5 a	12 a	0.5 ab	14 a
Fluroxypyr	34	0 a	0.0	1	2.3 b	64 ab	2.3 b	65 a
	68	0 a	0.0	0	1.4 ab	46 a	1.4 ab	46 a
Triclopyr	48	11 bc	1.3	31	5.7 c	139 b	7.0 c	170 b
	96	20 c	1.6	23	5.2 c	122 b	6.7 c	146 b
Untreated	—	94 d	0.1	4	0.3 a	22 a	0.4 a	26 a
Season								
One GSAT	—	18 A	0.3	4	3.1 B	53 A	3.5 B	57 A
Two GSAT	—	18 A	0.6	14	1.7 A	75 B	2.4 A	89 B

[a] Root collar sprouts include all new sprouts originating from the stump and root collar area within 2.5 cm of the stump base.

[b] Lateral root sprouts include all new sprouts within a 1-m radius of the root collar (3.14 m^2 area around each tree).

[c] Treatment means within columns followed by either the same uppercase or lowercase letter are not significantly different at $P = 0.05$.

different from the triclopyr ester treatments, which reduced foliar cover to 11 and 20% for the low and high rates, respectively (Table 4). In many cases, basally treated stems with zero foliar cover had already fallen because of decomposition. This was observed most commonly with the aminocyclopyrachlor treatments.

Similar to the cut stump study, sprouting from the root collar area was minimal across basal bark herbicide treatments, and most trees had no root collar sprouts. Lateral root sprout production, and therefore, total sprout production, was strongly influenced by herbicide treatment and GSAT ($P < 0.004$ for both main effects), and there were no significant interactions between herbicide treatment and GSAT.

Compared with the untreated control, the number of lateral root sprouts within 1-m of the root collar was higher for all basal bark herbicide treatments except the high rates of aminocyclopyrachlor and fluroxypyr. Both triclopyr rates resulted in greater lateral root sprouting than all other treatments and averaged 5.2 to 5.7 lateral sprouts (Table 4). The results for total sprout production were very similar to lateral sprout production. Additionally, similar to the cut stump study, both lateral root sprouts and total sprouts decreased from the end of the first GSAT to the end of the second GSAT.

Lateral root sprout height and total sprout height generally followed a similar pattern with significant herbicide treatment and GSAT main effects with no significant interaction between them. Both aminocyclopyrachlor and fluroxypyr resulted in lateral sprout heights and total sprout heights similar to the untreated control (Table 4). Both rates of triclopyr ester resulted in sprout growth that was greater than almost all other herbicide treatments. Across treatments, lateral and total sprout height increased from the end of one GSAT to two GSAT. This suggests that surviving lateral roots were able to overcome herbicide effects and were in the process of establishing new stems, independent of the original treated stems.

For the basal bark study, Chinese tallowtree rootstock mortality, defined as an experimental unit with zero foliar cover for the original treated stems and zero new sprouts from both the root collar and lateral roots within a 1-m radius, significantly differed among herbicide treatments. The high rate of aminocyclopyrachlor resulted in a significantly greater mortality rate (86%) at two GSAT than all other herbicide treatments, except the high rate of fluroxypyr (Table 3). Fluroxypyr at both rates and aminocyclopyrachlor at the low rate did not differ with respect to mortality (59 to 72%). Triclopyr treatments resulted in only 26% mortality, which was significantly less than all other herbicide treatments.

Foliar Treatment Study. For Chinese tallowtree foliar cover, there was a significant interaction between herbicide treatment and GSAT ($P = 0.003$). All herbicide treatments reduced foliar cover to 28% or less at one GSAT, and plants showed clear signs of herbicide damage. Aminocyclopyrachlor reduced foliar cover to 2% and was different than all other treatments except fluroxypyr (Table 5). Imazamox, which takes a greater time to illicit a response, reduced cover to 28% at one GSAT. However, by two GSAT, imazamox reduced foliar cover to 12%, which was similar to aminocyclopyrachlor. The aminopyralid and fluroxypyr treatments had less foliar cover than the untreated control had, but they had more foliar cover at

Table 5. Mean comparisons of Chinese tallowtree percent foliar cover 1 and 2 growing seasons after treatment (GSAT) with foliar applied herbicides. Statistical analysis was performed using the arcsin square root transformation. Nontransformed means are presented for clarity.

Herbicide	Rate	Foliar cover[a] One GSAT	Foliar cover[a] Two GSAT
	$g\ L^{-1}$	%	%
Aminocyclopyrachlor	1.5	2 a	16 a
Aminopyralid	0.6	16 b	58 b*
Fluroxypyr	1.5	12 ab	53 b*
Imazamox	2.4	28 b	12 a
Triclopyr	7.2	23 b	86 c*
Untreated	—	86 c	96 c

[a] Means within columns followed by the same letter are not significantly different at the 5% level using Fisher's protected LSD test. Means within rows followed by an asterisk differ between one and two GSAT.

two GSAT. Triclopyr amine foliar cover increased significantly between one and two GSAT and no longer differed from the untreated control at two GSAT.

There was a significant effect of herbicide treatment ($P < 0.001$) and GSAT ($P = 0.005$) on Chinese tallowtree root collar sprout and total sprout number. Aminocyclopyrachlor resulted in the fewest root collar sprouts compared with all other treatments (Table 6). Fluroxypyr was the only other treatment that reduced root collar sprout number compared with the untreated control. Total root sprouting declined as a function of herbicide treatment, similar to root collar sprouting (Table 6). Herbicide treatment also significantly influenced lateral sprout number ($P = 0.014$), but GSAT was not significant ($P = 0.114$). Although lateral root sprouting was generally low, aminocyclopyrachlor and imazamox were the only herbicide treatments that reduced lateral sprouting compared with the untreated control.

There was also a significant interaction between herbicide treatment and GSAT for root collar sprout height ($P < 0.001$) and total sprout maximum height ($P = 0.011$). Heights at 1 GSAT were more reflective of the speed of initial canopy brownout. For example, aminocyclopyrachlor and fluroxypyr reduced canopy height to a greater extent than did imazamox, whose mode of action takes longer to work. However, by two GSAT, imazamox was similar to aminocyclopyrachlor in maximum root collar sprout height, whereas significant recovery in maximum shoot height occurred with fluroxypyr (Table 7).

Table 6. Chinese tallowtree sprouting response to foliar herbicide treatment and growing season after treatment (GSAT).

Herbicide	Rate	Root collar sprouts[a] No.[c]	Lateral root sprouts[b] No.[c]	Lateral root sprouts[b] ht[c]	Total sprouts No.[c]
	$g\ L^{-1}$			cm	
Aminocyclopyrachlor	1.5	4.1 a	0.5 a	17 a	4.6 a
Aminopyralid	0.6	10.9 bc	2.0 c	51 bc	12.9 bc
Fluroxypyr	1.5	8.4 b	1.4 bc	47 bc	9.8 b
Imazamox	2.4	9.9 bc	1.0 ab	25 ab	10.8 bc
Triclopyr	7.2	14.4 bc	2.1 c	65 c	16.5 c
Untreated	—	14.7 c	1.6 c	75 c	16.4 bc
Season					
One GSAT	—	14.7 B	1.2 A	23 A	15.9 B
Two GSAT	—	6.1 A	1.7 A	71 B	7.8 A

[a] Root collar sprouts include all new sprouts originating from the stump and root collar area within 2.5 cm of the stump base.

[b] Lateral root sprouts include all new sprouts within a 1-m radius of the root collar (3.14 m^2 area around each tree).

[c] Treatment means within columns followed by either the same uppercase or lowercase letter are not significantly different at $P = 0.05$.

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Table 7. Mean comparisons of Chinese tallowtree root collar sprout heights one and two growing seasons after treatment (GSAT) with foliar applied herbicides. Statistical analysis was performed using the logarithmic transformation. Nontransformed means are presented for clarity.

Herbicide	Rate	Height[a]	
		One GSAT	Twp GSAT
	g L^{-1}	cm	
Aminocyclopyrachlor	1.5	47 a	24 a
Aminopyralid	0.6	76 bc	115 b
Fluroxypyr	1.5	68 ab	125 bc*
Imazamox	2.4	120 c	30 a*
Triclopyr	7.2	82 bc	180 c*
Untreated	—	202 d	310 d*

[a] Means within columns followed by the same letter are not significantly different at the 5% level using Fisher's protected LSD test. Means within rows followed by an asterisk differ between one and two GSAT.

A similar interaction was also observed for total maximum sprout height. Aminocyclopyrachlor did not change maximum sprout height between one and two GSAT, and imazamox significantly reduced total maximum sprout height between one and two GSAT. All other treatments resulted in significant height increases between one and two GSAT (Table 8).

Chinese tallowtree rootstock mortality, defined as a rootstock with zero foliar cover for the original treated stems and zero new sprouts from both the root collar and all lateral roots within a 1-m radius, significantly differed among herbicide treatments ($P < 0.001$).

Table 8. Mean comparisons of Chinese tallowtree total sprout numbers at one and two growing seasons after treatment (GSAT) with foliar-applied herbicides. Statistical analysis was performed using the logarithmic transformation. Nontransformed means are presented for clarity.

Herbicide	Rate	Height[a]	
		One GSAT	Two GSAT
	g L^{-1}	cm	
Aminocyclopyrachlor	1.5	57 a	47 a
Aminopyralid	0.6	98 ab	194 b*
Fluroxypyr	1.5	86 ab	195 b*
Imazamox	2.4	134 b	64 a
Triclopyr	7.2	107 b	275 bc*
Untreated	—	246 c	416 c*

[a] Means within columns followed by the same letter are not significantly different at the 5% level using Fisher's protected LSD test. Means within rows followed by an asterisk differ between one and two GSAT.

Aminocyclopyrachlor and imazamox resulted in the highest mortality at two GSAT of 67 and 56%, respectively, which were greater than triclopyr amine (Table 3). Imazamox took longer to kill rootstocks with only 8% mortality at one GSAT, compared with at 56% two GSAT. Aminopyralid resulted in 22% mortality and was similar to triclopyr amine. Fluroxypyr also resulted in low mortality (25%) and was highly variable and did not differ from any other herbicide treatment.

Discussion

In woody plants, the formation of new sprouts from dormant buds often occurs following damage and results in the production of secondary trunks (Del Tredici 2001) or shrubby thickets. This strategy increases survival following natural disturbances, such as fire or herbivory, and is a common trait of many woody native and invasive plants. Sprouting of woody invasive species is frequently exacerbated in managed ecosystems, where repeated anthropogenic disturbances both facilitate invasion through creation of open niches and facilitate sprouting through ineffective or partially effective management approaches. For example, Burch and Zedaker (2003) found that cutting tree-of-heaven [*Ailanthus altissima* (P. Mill.) Swingle] with no other management resulted in large increases in stand density. We observed this type of stem increase in our cut stump and foliar studies, when Chinese tallowtree was cut with no subsequent herbicide treatment. We also observed this for some herbicide treatments. This is somewhat troubling, given that this was observed for certain commercial standard herbicide treatments. Although follow-up monitoring and additional treatments are generally necessary to address new recruits from the seedbank and new sprouts from surviving root crowns or lateral roots, it is critical to provide land managers with tools that maximize initial control within each individual operation.

These data are the first reported detailed results, to our knowledge, concerning IPT methods for Chinese tallowtree control. We found that the commercial standard treatments of triclopyr (ester and amine formulations) did not always provide consistent control, especially to both root collar and lateral root sprouting. We found that aminocyclopyrachlor generally provided better control than triclopyr (i.e., it reduced foliar cover and root collar and lateral root sprouting) when applied with basal bark and foliar IPT methods. We also found that fluroxypyr often provided better Chinese tallowtree control than triclopyr did. Additionally, aminopyralid and imazamox provided better than or comparable control to triclopyr. Our data also provide the first look at both Chinese tallowtree root collar sprouting and lateral root sprouting following herbicide treatment, which is rarely reported for woody

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invasive plants. Additional research to better examine these newer herbicides for optimal rates and application timings could be very beneficial for increasing the herbicide portfolio for Chinese tallowtree management.

Given that previous herbicide recommendations for Chinese tallowtree were primarily developed in Florida, these data also suggest that control strategies may need to be better examined across the invaded range as it continues to spread throughout the southeastern United States. This may entail an integration of applied weed science management studies (integrated control techniques) with genetic and molecular studies (genotypic variation) and ecological studies (variation in invaded site characteristics). This combined research could potentially lead to powerful refinements and innovation in invasive plant management and development of new approaches.

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