EFFICACY OF HERBICIDE TREATMENTS FOR CONTROLLING RESIDUAL SPROUTING OF TREE-OF-HEAVEN

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Abstract.—Tree-of-heaven (*Ailanthus altissima* [Mill.] Swingle) is one of the most widely distributed exotic invasive tree species in the United States and has become naturalized throughout the central hardwood forest. It opportunistically establishes in areas associated with silvicultural regeneration treatments and extirpation often requires the targeting of individual trees due to the close proximity of native co-occurring stems. Further, tree-of-heaven is a prolific root and stump sprouter, and extirpating this exotic invasive tree species requires not only killing the aboveground stem but also ensuring that lateral roots are killed. The study was designed to test the efficacy of five individual tree treatments in killing stems and preventing sprouting: EZ-Ject® (granulated glyphosate), full basal bark (triclopyr ester), hack and squirt (picloram/2,4-D), hack and squirt (glyphosate), and tree injection (picloram/2,4-D). The mortality and sprouting of sapling-sized tree-of-heaven developing in two naturally regenerating hardwood stands were investigated. We treated 410 stems. Treatments provided effective top kill compared to the untreated control group with treatment top dieback figures ranging from 91 to 100 percent compared to less than 15 percent for the untreated control. Treatment areas were examined for the occurrence and type of sprouts (basal stem, root collar, and lateral root). The EZ-Ject® glyphosate treatment exhibited 33-percent total sprouting in 2006 and 5 percent in 2007 compared to a range of 3 to 12 percent for other treatments in 2006 and 0 to 2 percent for all other treatments in 2007. This study indicates that all forms of sprouting should be considered when control options are tested and that EZ-Ject® applications with glyphosate may not provide thorough control of sprouting.

INTRODUCTION

Tree-of-heaven (*Ailanthus altissima* [Mill.] Swingle) is an exotic invasive tree species introduced into the United States in the 18th century; it is now naturalized throughout much of North America (Burch and Zedaker 2003). It is an invasive pioneer species, showing prolific root and stump sprouting, producing large amounts of seed, and undergoing rapid juvenile growth, with the potential to create pure stands where it invades (Burch and Zedaker 2003). Tree-of-heaven is phenotypically plastic, adjusting to various temperature, humidity, light, and moisture levels (Meloche and Murphy 2006), and is not limited by soil stoniness or pH, or urban pollution levels (Burch and Zedaker 2003). The species typically invades along forest edges, infiltrating the interior forest by way of roads, trails, and disturbance gaps (Meloche and Murphy 2006). Though the species is intermediate to intolerant of shade, root sprouts from its shallow, spreading root system grow slowly and can survive for years under an intact canopy, enabling this species to respond to disturbance (Burch and Zedaker 2003, DiTomaso and Kyser 2007). These ecological factors contribute heavily to tree-of-heaven's ability to invade disturbed areas in central hardwood forests, and spread into undisturbed areas.

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While management for tree-of-heaven is not yet well established (Meloche and Murphy 2006), several studies over the past few years have begun to explore control methods (Johnson and others 2001, Burch and Zedaker 2003, Lewis and McCarthy 2006, Meloche and Murphy 2006, DiTomaso and Kyser 2007, Lewis 2007, Lewis and McCarthy 2008). Studies have found that control methods without herbicide application result in worsening the infestation through the abundance of basal and lateral root sprouting (Pannill 2009, Burch and Zedaker 2003, Meloche and Murphy 2006, DiTomaso and Kyser 2007). Among studies that did use herbicide control, however, results have been mixed. Burch and Zedaker (2003) found that various full basal bark treatment combinations of triclopyr, imazapyr, and picloram all completely controlled stump sprouting. The best top kill resulted from a combination of 20 percent triclopyr and 5 percent picloram (Burch and Zedaker 2003). DiTomaso and Kyser (2007) looked at triclopyr, imazapyr, and glyphosate use in four different treatment types: cut stump, full basal bark spray, stem injection, and stump injection. They found that imazapyr provided good control of stems 1.6 to 6.4 inches in diameter at knee height, and a 75-percent reduction in sprouting percent and sprout size for all types of sprouts, compared to treatments without herbicides. The cut stump treatments with imazapyr and triclopyr both provided excellent control of all sprouts compared to the glyphosate treatment; however, stump injection provided unacceptable control regardless of herbicide, and stem injection provided the best control with imazapyr and glyphosate, but not with triclopyr (DiTomaso and Kyser 2007). Finally, imazapyr and triclopyr both provided excellent control when used as a full basal bark spray (DiTomaso and Kyser 2007). Johnson and others (2001) found that triclopyr alone or in combination with imazapyr in a full basal bark spray provided effective canopy mortality and sprout control. Lewis (2007) found that stem injection using the EZ-Ject® (distributed by ArborSystems, Omaha, NE) herbicide system resulted in effective stem mortality with use of imazapyr and glyphosate, but not with triclopyr, though all three herbicides completely controlled sprouting. Meloche and Murphy (2006) found that a cut stump treatment with glyphosate was most effective at managing juvenile stems (less than 23.6 inches in height and less than 2 inches in diameter at breast height [d.b.h.]) that were too small on which to effectively use EZ-Ject®. EZ-Ject® with glyphosate effectively controlled more mature stems (greater than 23.6 inches in height and greater than 2 inches d.b.h.) but did not effectively control sprouts.

Our study reports the results of treating tree-of-heaven stems ranging from 0.1 to 3.9 inches d.b.h. in two naturally regenerating hardwood stands with five methods: tree injection using the EZ-Ject® lance with glyphosate capsules, full basal bark application using 25-percent triclopyr (Garlon 4® [Dow AgroSciences LLC, Indianapolis, IN]), hack and squirt using 100-percent picloram/2,4-D (Pathway [Dow AgroSciences]), liquid tree injection with 100-percent picloram/2,4-D (Pathway®) using the Jim-Gem® tree injector (Forestry Suppliers, Jackson, MS), and hack and squirt with 100-percent glyphosate (Accord® [Dow AgroSciences]). The objective of our study was to increase the amount of available tree response data on herbicide options for controlling existing stems as well as basal stem, root collar, and lateral root sprouting of tree-of-heaven.

STUDY AREAS

This study took place during the growing seasons of 2006 and 2007 on the University of Kentucky's Robinson Forest, a 15,000-acre experimental forest located in Breathitt, Knott, and Perry Counties in eastern Kentucky. The forest is in the southern section of the central hardwood forest region (longitude -83.14°W, latitude 37.47°N), and is composed of mixed mesophytic and oak-hickory forest types. Two stands were used for this study. Stand 1 is located on the upper third of a southwest-facing slope. Stand 2 occurs on the upper third of a north-facing slope. Both stands received a deferment harvest, retaining 10-15 ft^2 of basal area per acre of dominant and co-dominant trees. The stands were allowed to regenerate naturally and tree-of-heaven invaded

the stands during this time. Individual tree-of-heaven stems were scattered throughout the native regenerating age class. Stand 1 regenerating age class averaged 2 to 3 inches d.b.h. and was 8 years old. Stand 2 regenerating age class averaged 1 to 2 inches d.b.h. and was 5 years old. We treated 213 tree-of-heaven stems (0.2 to 3.9 inches d.b.h.) in June 2006 and 197 tree-of-heaven stems (0.1 to 2.3 inches d.b.h.) in June 2007.

MATERIALS AND METHODS

Each of five two-person crews was randomly assigned one of the treatments. Crews were then randomly assigned transects approximately 20 feet in width through each of the stands. Individual tree-of-heaven stems were treated and marked for future measurements. No other species were treated.

Table 1 shows the five treatments, number of stems treated by treatment type, and year treated. Treatments were as follows: (1) EZ-Ject® herbicide system with glyphosate capsules, at the manufacturer's recommended rate of one capsule per stem for trees less than 2.5 inches d.b.h. and one capsule for every 4 inches of circumference for trees larger than 2.5 inches d.b.h.; (2) full basal bark spray with 25 percent triclopyr (Garlon 4® and 75 percent nonpolar carrier, wetting the entire circumference of the lower 16 inches of the stem; (3) hack and squirt, using 0.03 fl. oz. of undiluted Pathway® per 2 to 3 inches of stem circumference; (4) tree injector with 0.03 fl. oz. of undiluted (Pathway® per 2 to 3 inches of stem circumference; and (5) hack and squirt with 0.03 fl. oz. of undiluted Accord® per 2 to 3 inches of stem circumference. In 2006, 50 tree-of-heaven stems scattered throughout the treated stand were missed during treatment implementation and were used as untreated controls for the study. No stems were missed during 2007, so there is no control for that year.

One year after herbicide treatment, all treated stems were placed into percent top dieback classes, using a visual estimate of the canopy area that had died since the treatment. Each treated stem was surveyed for associated sprouts. Each sprout was classified as to its provenance, falling into one of three categories: lateral root (lateral root sprouts that were difficult to visually assign to individual stems were excavated and traced to the parent tree), root collar, or basal stem (those sprouts occurring between the root collar and approximately 1 foot above the ground).

The GLM procedure of the SAS statistical software package (SAS Institute, Cary, NC) was used to determine whether there were differences in the percent of treated stems with sprouts (100*[# of stems with sprouts/ total stems treated per treatment]), at the α=0.05 level. Years 2006 and 2007 were analyzed separately.

Table 1.—Five treatments used for tree-of-heaven control in this study, including delivery method, herbicide used, and total number of stems treated by year.

Treatment	Delivery method	Herbicide	No. of stems treated 2006	No. of stems treated 2007
0 (control)	None	None	50	0
1	EZ-Ject® lance	Glyphosate	18	43
2	Basal bark spray	Triclopyr	38	48
3	Hack and squirt	Picloram/2,4-D	39	26
4	Jim-Gem® tree injector	Picloram/2,4-D	34	39
5	Hack and squirt	Glyphosate	84	41

RESULTS

Overall, average top dieback was greater than 91 percent for all treatments in both years (Table 2), compared to 14 percent for the untreated control group in 2006.

Table 3 shows the percent of treated tree-of-heaven stems with living sprouts 1 year after treatment. In 2006, 12 percent of the untreated control group exhibited living sprouts, which was not statistically different from all other treatments, with the exception of the EZ-Ject glyphosate treatment. The EZ-Ject® with glyphosate treatment resulted in 33 percent of the trees sprouting, significantly higher than the other treatments, which ranged from 3 to 12 percent (Table 3). Sprouting for the EZ-Ject® glyphosate treatment was composed of 28 percent lateral root sprouts, 66 percent root collar sprouts, and 6 percent basal stem sprouts (Table 4).

Table 2.—Average percent top dieback by treatment and year.

Treatment	Delivery method	Herbicide	Average percent top dieback 2006	Average percent top dieback 2007
0 (control)	None	None	14	
1	EZ-Ject® lance	Glyphosate	100	100
2	Basal bark spray	Triclopyr	91	100
3	Hack and squirt	Picloram/2,4-D	100	96
4	Jim-Gem® tree injector	Picloram/2,4-D	100	100
5	Hack and squirt	Glyphosate	96	96

Table 3.—Percent treated stems with sprouts by treatment and year. Letters show differences among population means within that year.

Treatment	Delivery method	Herbicide	Percent treated stems with sprouts 2006	Percent treated stems with sprouts 2007
0 (control)	None	None	12 a	
1	EZ-Ject® lance	Glyphosate	33 b	5 a
2	Basal bark spray	Triclopyr	3 a	0 a
3	Hack and squirt	Picloram/2,4-D	3 a	0 a
4	Jim-Gem® tree injector	Picloram/2,4-D	12 a	0 a
5	Hack and squirt	Glyphosate	11 a	2 a

Table 4.—Location of sprouts by treatment and year. Figures are percent of total sprouts in each location.

			Percent of total sprouts from lateral root		Percent of total sprouts from root collar		Percent of total sprouts from basal stem	
Treatment	Delivery method	Herbicide	’06	’07	’06	’07	’06	’07
0 (control)	None	None	37		0		64	
1	EZ-Ject® lance	Glyphosate	28	64	66	0	6	36
2	Basal bark spray	Triclopyr	100	0	0	0	0	0
3	Hack and squirt	Picloram/2,4-D	100	0	0	0	0	0
4	Jim-Gem® tree injector	Picloram/2,4-D	75	0	25	0	0	0
5	Hack and squirt	Glyphosate	53	0	47	0	0	100

For the 2007 treatments, the EZ-Ject® with glyphosate exhibited 5 percent stems with living sprouts, compared to hack and squirt with glyphosate at 2 percent (Table 3). The basal bark treatment with triclopyr, hack and squirt with picloram/2,4-D, and tree injector with picloram/2,4-D all showed no indications of sprouting. None of the 2007 treatments were statistically different. Sprout location percentages are shown in Table 4.

DISCUSSION

The project provided information relative to sprouting of tree-of-heaven subjected to methods and herbicides commonly used for eradication and control. Sprouting, particularly from lateral roots, is important to understand and control, especially for this species, which has a high propensity for this type of response to top kill. All of the treatments incorporating glyphosate, triclopyr, and picloram/2,4-D resulted in levels of top kill that would be viewed as an operational success (> 91 percent).

All of the treatments with the exception of the EZ-Ject® with glyphosate were found to produce no more sprouting than was associated with trees that were not treated. In 2006, 33 percent of EZ-Ject® glyphosate-treated stems showed live sprouts 1 year after treatment. In 2007, no method was statistically different from any other, but we noted a trend associated with a higher average sprouting percentage for the glyphosate treatments compared to the others. Meloche and Murphy (2006) also found that the EZ-Ject® with glyphosate did not effectively control sprouting. It is possible that the EZ-Ject® does not sufficiently distribute the glyphosate around the stem, leaving strips of cambium alive that contribute to the higher incidence of sprouting, or that this method does not provide for a sufficient amount of active ingredient at the recommended application rate. Without testing the EZ-Ject® applicator with the other herbicides as well as with glyphosate, however, it is not possible to determine whether the glyphosate or the application technique resulted in reduced sprouting control.

Similarly to Burch and Zedaker (2003) and DiTomaso and Kyser (2007), our study found that triclopyr in a basal bark spray provided effective sprout control. Picloram/2,4-D also provided effective sprouting control in our study, when used both with the hack and squirt method and with the tree injector.

Several combinations of herbicide and delivery method will work to control existing stems of tree-of-heaven. As shown by the results of this study and others in the references above, glyphosate, triclopyr, and picloram alone or in combination with 2,4-D, and imazapyr, all provide good control of aboveground stems with various delivery methods. However, some considerations with using picloram or imazapyr should be taken into account before their use in controlling tree-of-heaven. Picloram is not registered for use in California or near water in any state, calling for another choice of herbicide in those situations (DiTomaso and Kyser 2007). Imazapyr, a commonly used chemical for hardwood control, has been found to have nontarget activity both when used as a basal bark spray and when directly injected into the target stem. One study found that using imazapyr in a basal bark spray left a dead zone of 3.3 ft. around the base of the target stem, and the authors mention that it is a broader-spectrum herbicide with longer residual activity and may not be a good choice in situations with nearby desirable stems (DiTomaso and Kyser 2007). Another study found that imazapyr, when directly injected into the target tree-of-heaven stem using the EZ-Ject® lance at the manufacturer's recommended rate, translocated and killed an average of 2.5 nontarget nearby stems, of both tree-of-heaven and other species, with damage seen up to10 ft. away from the injected stem (Lewis and McCarthy 2008). Given the other choices, imazapyr should be used only in situations where the risk to other nearby stems is minimal, as with a pure stand of undesirable species (Lewis and McCarthy 2008).

CONCLUSIONS

The larger issue with tree-of-heaven is not control of existing stems, but sufficient suppression of sprouting so that the infestation is not made worse by an abundance of sprouts. Based on our study and the others reviewed here, picloram and imazapyr have excellent sprout control, and triclopyr provided excellent sprout control except when applied by the hack and squirt method by DiTomaso and Kyser (2007). However, there is a proliferation of evidence that glyphosate does not provide sufficient sprout control. In the first year of our study, the EZ-Ject® lance with glyphosate was the only treatment that was statistically worse than all other methods, though hack and squirt with glyphosate was not different from any other method. Meloche and Murphy (2006) also did not have success with control of sprouts using glyphosate in the EZ-Ject®, and DiTomaso and Kyser (2007) report that glyphosate did not sufficiently control sprouting in a cut stump treatment. Lewis (2007) did have success with the EZ-Ject® lance and glyphosate in controlling sprouts, though that study is somewhat of an anomaly, as no sprouting was reported after any treatment option (Lewis and McCarthy 2006, Lewis 2007).

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