USING HERBICIDES TO CONTROL INTERFERING UNDERSTORIES IN ALLEGHENY HARDWOOD STANDS

2. SHARPENING THE TOOLS IN THE TOOLBOX

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Insights for Managers

Recent studies have confirmed the following guidelines for herbicide use to create conditions that are favorable for establishing and growing desirable seedlings:

- **For control of fern interference alone in Allegheny hardwood or mixed-oak forests, SILVAH recommends herbicide when more than 30 percent of regeneration plots have more than 30 percent fern interference.**
  - **If seedlings are already present, SILVAH recommends sulfometuron methyl at 2 ounces per acre in 25 gallons of water without surfactant. Surfactants in this situation cause seedling mortality.**
  - **If no seedlings are present, SILVAH recommends the same treatment as for woody interference.**
- **For woody interference in Allegheny hardwood stands, SILVAH recommends herbicide when more than 30 percent of regeneration plots have more than 30 percent high or low woody interference, or when the overstory inventory shows more than 10 square feet of basal area of interfering species in sapling and pole size classes.**
  - **For these situations, SILVAH recommends glyphosate-containing herbicide formulations at 1.5 quarts in 25 gallons of water per acre.**
  - **Timing of application is important: the best results are achieved mid-July through August.**
  - **The most effective surfactant mixed with glyphosate for control of shorter and tall striped maple was the proprietary surfactant included in Roundup Pro Max®,[2] which is labeled for forestry use.**
  - **In Allegheny hardwood stands, managers give up a cohort of established seedlings when they treat woody interference with glyphosate.**
  - **In mixed-oak forests, SILVAH recommends glyphosate to treat woody interference only in the absence of an oak seedling cohort.**

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INTRODUCTION

Dense rhizomatous herbaceous ferns such as hay-scented fern (*Dennstaedtia punctilobula*) and New York fern (*Thelypteris noveboracensis*), graminoids such as bearded shorthusk (*Brachelytrum erectum*), *Danthonia* spp., and *Carex* sp. ground cover, and woody understories of striped maple (*Acer pensylvanicum*), American beech (*Fagus grandifolia*), and sweet birch (*Betula lenta*) are found throughout the Allegheny Plateau region and beyond (Allegheny National Forest 1995, Horsley 1991). Considerable evidence suggests these ground cover layers are caused by long-term browsing by overabundant white-tailed deer (Horsley et al. 2003, Tilghman 1989). Once these plants occupy the understory, they interfere strongly with the regeneration and establishment of desirable woody species (Horsley 1993a, 1993b; Horsley and Marquis 1983).

Established methods for controlling interfering plants have been used since the 1980s (Horsley 1988b, Horsley and Bjorkbom 1983, Horsley and Marquis 1983). Earlier research in the Allegheny hardwood type showed that a tank mix of the herbicides glyphosate and sulfometuron methyl effectively, economically, and safely removes interfering plants and minimizes their impact on regeneration so desirable hardwood species can become established (Horsley 1981, 1982, 1988a, 1990a, 1990b, 1991, 1994; Horsley and Marquis 1983; McCormick et al. 1991). The herbicide application is typically associated with a shelterwood seed cut to promote the establishment of desirable woody species (Horsley and Marquis 1983). Since the early research was completed, changes in products labeled for forestry use and differences among contractors often have resulted in operational reports of unacceptable and incomplete control of the targeted species.

When USDA Forest Service scientists hosted a collaborators' meeting in the early 2000s, foresters and silviculturists suggested they have all the tools they need (herbicides, fertilizers, cutting methods, and equipment), but the tools need to be refined and reshaped for emerging problems. Inadequate striped maple control and inadequate control of ferns using Oust® were enough of a concern that the Pennsylvania Department of Conservation and Natural Resources Bureau of Forestry funded three herbicide studies to allow us to sharpen the herbicide tool that was routinely used across that state. The research included:

- A study to evaluate the control of striped maple when imazapyr was added to the herbicide mix.
- A study of surfactants used with glyphosate to control striped maple.
- An expanded study of Oust® control of ferns and its impacts on various tree seedlings.

THE IMAZAPYR STUDY

Methods

Six 32-acre sites were chosen on the Susquehannock State Forest, all with quite uniform striped maple understories. Each site was separated into eight 4-acre treatment units. Each site included one untreated control, one scarified control (run over with equipment without spraying), and 0, 1, or 2 ounces of imazapyr applied in either July or August. A skidder-mounted mist blower was used to apply herbicides with a tank mix of 1.5 quarts of glyphosate, 2 ounces of sulfometuron methyl, and one of the imazapyr rates in 25 gallons of water per acre. Three sites were treated in 2004 and the other three in 2005. Tree species regeneration was evaluated using 10 milacre plots per treatment. Inventories were done pretreatment and 1, 2, and 5 years after treatment. Striped maple and beech control were evaluated at year 2 and

Table 1.—Percentage striped maple mortality using 1.5 quarts glyphosate and 2 ounces sulfometuron methyl alone or in combination with 1 ounce or 2 ounces imazapyr per acre. Numbers in parentheses are standard error of the mean. Values within a height class and year followed by the same letter are not significantly different at p <0.05.

			1.5 quarts glyphosate and 2 ounces sulfometuron methyl					
			No imazapyr		1 ounce imazapyr		2 ounces imazapyr	
Striped maple	Control	Scarified control	July	August	July	August	July	August
			Percent mortality 2 years after treatment					
<15 ft	22.2[a]	11.9[a]	62.8[b]	52.2[bc]	63.7[b]	55.6[bc]	61.3[b]	49.5[c]
	(3.7)	(2.3)	(4.6)	(4.1)	(3.5)	(3.7)	(4.2)	(4.4)
>15 ft	17.9[a]	3.5[b]	65.9[c]	57.9[c]	61.8[c]	67.0[c]	72.0[c]	51.5[c]
	(5.6)	(1.6)	(6.2)	(7.0)	(5.7)	(7.1)	(6.4)	(6.5)
			Percent mortality 3 years after treatment					
<15 ft	29.0[a]	18.6[a]	88.4[b]	72.8[c]	65.7[c]	70.8[c]	67.5[c]	75.7[bc]
	(12.1)	(5.5)	(2.8)	(10.7)	(7.9)	(5.3)	(10.0)	(6.0)
>15 ft	12.5[a]	4.6[a]	62.1[bc]	62.3[bc]	62.3[bc]	80.8[b]	77.9[bc]	65.2[c]
	(10.0)	(3.2)	(13.9)	(8.7)	(8.7)	(10.4)	(11.2)	(14.8)

year 3 on ten 1-100th acre plots with a center coincident with the regeneration plots. All sites were fenced with electric deer exclosures to reduce deer impact on seedlings. SAS version 9.4 (SAS Institute Inc. 2011) was used to conduct all statistical analyses. See the appendix on page 55 for details.

Results

Striped maple control did not increase significantly by adding 1 or 2 ounces of imazapyr to a tank mix with glyphosate. In untreated control plots, mortality of striped maple shorter than 15 feet (shorter striped maple) was 29 percent after 3 years and was 12.5 percent for striped maple taller than 15 feet (tall striped maple) (Table 1). Percent mortality after herbicide treatment was higher for year 3 than year 2, suggesting a delayed effect for the trees to succumb to herbicide treatment (Table 1). Tall striped maple crowns are usually higher than ground spray equipment can reach; therefore, the entire crown often is not treated. Less chemical is thus absorbed and translocated. The 3-year postherbicide mortality ranged from 62 percent to 81 percent (Table 1). Shorter striped maple was best controlled in stands treated with glyphosate and sulfometuron methyl alone (88 percent mortality). Treatment in July without imazapyr resulted in significantly higher mortality than all other formulations and timing combinations, except for stands treated with 2 ounces of imazapyr in the mix applied in August (75.7 percent) (Table 1). These results showed that all formulations produced essentially the same results for shorter and tall striped maple, though average mortality was higher in some treatments including imazapyr, but none of these were statistically significant. Land managers in the region have suggested that they observe better control of all striped maple when imazapyr is included in the mix. However, results of this study do not support their observation for control of shorter striped maple and are mixed at best for tall striped maple.

Another question arose about whether applications of imazapyr had any negative or positive effects on regeneration development. Five species (American beech, black cherry, red maple, striped maple, and sweet birch) made up most of the seedling regeneration in this study. The results presented are limited to the end point of the study (5 years) (Table 2). For seedlings taller than 1 foot, only red maple showed significant differences between treatments. The 5,283 red maple seedlings per acre in stands treated with glyphosate and sulfometuron methyl

Table 2.—Seedlings present (number per acre) 5 years after treatment with herbicides including 1.5 quarts glyphosate, 2 ounces sulfometuron methyl, and 0, 1, or 2 ounces imazapyr applied in July or August. Numbers in parentheses are standard error of the mean. Values within a species row followed by the same letter are not different at p <0.05.

			1.5 quarts glyphosate and 2 ounces sulfometuron methyl					
			No imazapyr		1 ounce imazapyr		2 ounces imazapyr	
Species	Control	Scarified control	July	August	July	August	July	August
			Seedlings per acre shorter than 1 foot					
American beech	933^{a}	680^{a}	383^{a}	517^{a}	433^{a}	467^{a}	514^{a}	413^{a}
	(415)	(235)	(147)	(176)	(156)	(258)	(258)	(136)
Black cherry	44 400^{ab}	40 160^{ab}	61 933^{ab}	52 900^{ab}	56 600^{ab}	96 917^{cd}	97 343^{cd}	23 058^{bd}
	(17 254)	(7473)	(16 624)	(2 5113)	(20 665)	(25357)	(27391)	(5468)
Red maple	19 417^{a}	8860^{a}	53 300^{ab}	63 983^{b}	67 250^{b}	42 533^{ac}	76 500^{bc}	16 949^{acd}
	(10 022)	(4242)	(24 831)	(30 192)	(30 582)	(18156)	(32659)	(6458)
Striped maple	1517^{a}	2760^{a}	7017^{b}	3900^{ab}	3567^{ab}	3000^{ac}	2986^{abc}	3396^{ac}
	(389)	(1139)	(2218)	(1534)	(1031)	(836)	(1412)	(2427)
Sweet birch	33^{a}	580^{ab}	617^{b}	2133^{bc}	1017^{abc}	1050^{abc}	1314^{abc}	2651^{c}
	(33)	(580)	(430)	(1726)	(653)	(542)	(1134)	(1439)
			Seedlings per acre taller than 1 foot					
American beech	1400^{a}	1760^{a}	167^{a}	850^{a}	283^{a}	400^{a}	286^{a}	953^{a}
	(658)	(609)	(92)	(304)	(207)	(181)	(167)	(555)
Black cherry	83^{a}	480^{a}	1150^{a}	150^{a}	1183^{a}	1150^{a}	600^{a}	204^{a}
	(83)	(455)	(798)	(131)	(751)	(931)	(600)	(63)
Red maple	267^{a}	100^{a}	867^{ab}	5283^{b}	1067^{abc}	1350^{abc}	686^{c}	3696^{abc}
	(247)	(77)	(576)	(4375)	(648)	(1054)	(686)	(3168)
Striped maple	567^{a}	480^{a}	1000^{a}	550^{a}	567^{a}	533^{a}	529^{a}	467^{a}
	(128)	(229)	(515)	(293)	(238)	(217)	(219)	(101)
Sweet birch		180^{b}	733^{abc}	217^{ab}	633^{abc}	567^{abc}	543^{abc}	1571^{c}
	0^{a}	(156)	(733)	(217)	(633)	(528)	(543)	(966)

without imazapyr was the greatest number of all stems taller than 1 foot. In general, removing striped maple and American beech increased seedling development of the more desirable species. Black cherry seedlings shorter than 1 foot averaged 44,000 seedlings per acre on control plots but ranged from 52,900 to 97,343 stems per acre across all treated plots, except for plots treated with 2 ounces of imazapyr in August, when there were 23,058. Red maple had a similar response with 19,417 seedlings shorter than 1 foot on control plots and ranged from 42,533 to 76,500 stems per acre on treated plots, except for the 2-ounce imazapyr treatment in August, which had 16,949 stems per acre. Imazapyr had no lasting negative impact, except when 2 ounces per acre were applied in August. This resulted in fewer red maple and black cherry seedlings. None of the differences were significant for seedlings taller than 1 foot.

THE SURFACTANT STUDY

Methods

Six 32-acre sites were chosen in three Pennsylvania State Forests, two on the Susquehannock State Forest, two on Elk State Forest, and two on the Moshannon State Forest. All herbicide treatments to striped maple dominated understories included 1.5 quarts of glyphosate and 2 ounces of sulfometuron methyl per acre. An untreated control plot, an herbicide without surfactant treatment and herbicide treatments with six different surfactants were made at each site. The midpoint of the label-suggested rate range (shown in parentheses after each surfactant's name) was used for each surfactant added to the tank mix. Surfactants used included Cide-Kick II^{TM} (12 ounces), Kingpin (12 ounces), Surf-AC® 910 (6 ounces), Chemsurf^{TM} 90 (10 ounces), Monsanto's Roundup PROMAX® proprietary formulation (in mix), and Liberate® with LECI-TECH® (12 ounces). Tree species regeneration was evaluated using 20 milacre plots per treatment. Striped maple and beech control were evaluated on five 1-100th acre plots located randomly within each treatment area for 2 years after treatment. Areas were not fenced but had relatively low deer impacts. SAS version 9.4 (SAS Institute 2011) was used to condut statistical analyses. See the appendix on page 55 for details.

Results

Early research on herbicide to control striped maple used glyphosate as Roundup®, which contained a proprietary surfactant known as MON0818, later marketed as Entry 2. It was a polyethoxylated tallow amine that was implicated in negative impacts on amphibians. Changes in formulation led to use of glyphosate products without a surfactant. Managers began using various surfactants, but no research had been conducted into which ones worked best. The surfactant study conducted here tested for differences between the six surfactants and herbicide without surfactant. Like the arsenal study, the study detected a background mortality of 12 percent in smaller striped maple (shorter than 15 feet) and 4 percent in large striped maple (taller than 15 feet). The proprietary surfactant in Roundup ProMax® is different than original Roundup® and outperformed all other surfactants except KingPin in shorter striped maple (Fig. 1). Glyphosate with no surfactant resulted in 50 percent mortality in shorter striped maple. All other surfactants—Chemsurf^{TM} 90, Cide-Kick II^{TM}, Liberate®, and Surf-AC® 910—resulted in about 60 percent mortality after 2 years (Fig. 1A). For tall striped maple, Roundup® resulted in the best control, but was only statistically better than Surf-AC® 910 (Fig. 1B). Tall striped maple mortality was 20–25 percent with all surfactants except Roundup®, which was 40 percent. There was some concern about whether these surfactants changed the efficacy of glyphosate on American beech mortality. Mortality was 90 percent or higher for small American beech, except for Cide-Kick II^{TM}, which resulted in 60 percent mortality on average, lower than no surfactant at all. Taller American beech were not well represented in the data, and statistical tests could not be conducted. Results verify that glyphosate is still an effective tool in the toolbox for striped maple control (perhaps as Roundup PROMAX®, which is now labeled for forestry use).

REVISITING THE OUST® PRESCRIPTION

Methods

Five sites that fit the broad-scale criteria of having a fern interference problem and presence of seedlings beneath the fern were obtained from the Clear Creek, Cornplanter, Elk, Moshannon, and Susquehannock Districts of the Pennsylvania Bureau of Forestry. The sites selected were reasonably uniform in overstory basal area, ground cover, regeneration, and site conditions. Site limitations such as excessively wet or rocky soils were not permitted. Within each site, 24 treatment plots were selected by walking through the general area of the stand looking for locations with at least 5 seedlings in a dominating fern cover area. The 24 treatment plots were established in groups of 4 to allow for 4 rates of herbicide (0, 2, 3, or 4 ounces per acre), with the 6 groups representing different treatment times (June, July, August 2013 or 2014). Milacre plot centers were established within a 10-foot × 10-foot treatment area. Treatment times and rates were assigned randomly. A garden sprayer was used to apply the herbicide. Plots were not fenced and experienced browsing, but it was not consistent or widespread. Before treatment and full fern expansion (May 15-30), plant inventories were conducted on milacre

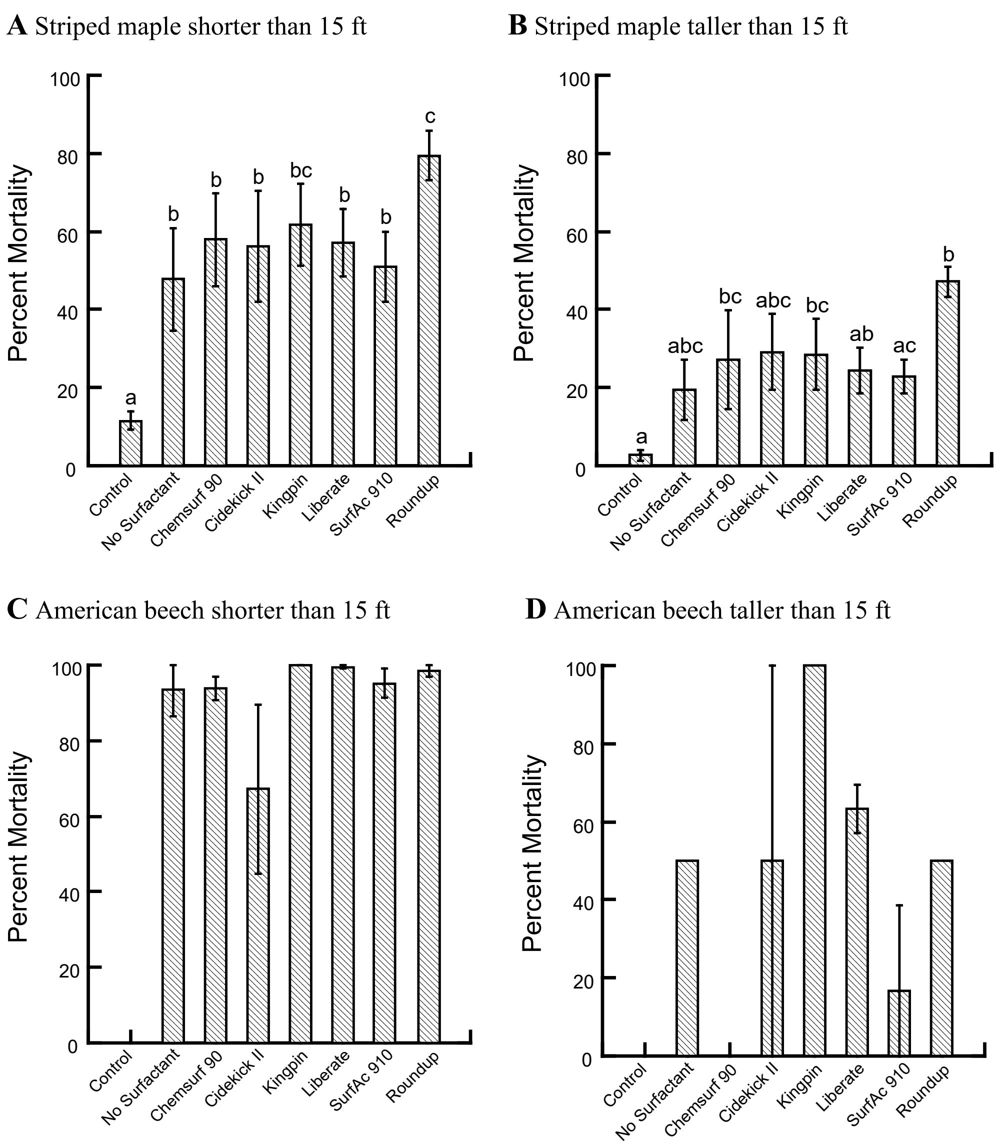

Figure 1.—Mortality, as a percentage, following herbicide application using different surfactants with glyphosate to control striped maple and American beech after 2 years. Bars followed by the same letter are not significant at p <0.05. Too few data were available for American beech to make statistical comparisons.

plots counting all tree seedlings by species and estimating percent of plot covered by broad classes of herbaceous plants, including the targeted fern species. Inventories were repeated 1 and 2 years after treatment to assess fern control and impacts on nontarget species. SAS version 9.4 (SAS Institute Inc. 2011) was used to conduct statistical analyses. See the appendix on page 55 for details.

Results

When the interfering plant problem species is rhizomatous fern cover in the presence of desirable advance regeneration, sulfometuron methyl at 2 ounces per acre is the recommended treatment (Horsley 1988b), generally applied in late August or September. Earlier research was limited geographically, and the current study expanded the region and the species that were evaluated. The three rates tested in this revisited study all reduced hay-scented fern coverage in the first year (Table 3). After 2 years, fern cover recovered substantially from 11.4 to 13.8 percent with September sulfometuron methyl treatments at all 3 rates. July

Table 3.—Percentage cover of herbaceous plants by time and rate of Oust® application. Values in parentheses are standard error of the mean. Numbers are from 10 replicates throughout north-central Pennsylvania. Significant (p <0.05) pairwise differences between pretreatment and post-treatment are indicated in bold. Rates and times showed no significant differences. Numbers in parentheses are standard error of the mean.

		Percent cover by species encountered on study plots											
		July (ounces Oust® /acre)				August (ounces Oust® /acre)				September (ounces Oust® /acre)			
	Year	0	2	3	4	0	2	3	4	0	2	3	4
Hay-scented fern	Pre	48.8	41.4	40.1	44.7	40.9	42.5	45.7	44.3	52.7	48.1	46.5	49.4
		(5.7)	(4.6)	(5.0)	(6.3)	(5.0)	(4.3)	(4.6)	(5.0)	(3.8)	(4.8)	(5.0)	(4.8)
	1 year	67.1	**0.4**	**0.3**	**0.0**	67.0	**0.6**	**0.5**	**0.4**	73.3	**1.9**	**2.9**	**1.8**
		(5.6)	**(0.2)**	**(0.1)**	**(0.0)**	(6.1)	**(0.2)**	**(0.2)**	**(0.2)**	(3.5)	**(0.6)**	**(1.1)**	**(0.6)**
	2 year	64.9	**1.0**	**0.7**	**0.3**	60.7	**1.4**	**2.2**	**1.3**	64.2	**11.4**	**12.3**	**13.7**
		(4.4)	**(0.3)**	**(0.3)**	**(0.1)**	(6.1)	**(0.5)**	**(1.0)**	**(0.5)**	(4.2)	**(2.9)**	**(4.0)**	**(4.2)**
Lycopodium spp.	Pre	1.8	3.2	4.5	3.9	1.1	5.1	6.6	2.6	8.4	2.6	0.6	2.9
		(1.6)	(3.2)	(3.7)	(3.9)	(1.1)	(4.5)	(4.8)	(2.6)	(5.4)	(1.5)	(0.5)	(2.4)
	1 year	3.8	1.6	4.5	4.3	0.1	5.1	9.2	3.2	8.7	5.3	1.3	4.3
		(2.6)	(1.2)	(3.4)	(4.2)	(0.1)	(4.2)	(5.3)	(3.2)	(4.7)	(3.4)	(1.3)	(3.3)
	2 year	1.8	1.9	4.7	2.9	1.1	4.7	6.8	3.3	7.8	6.9	0.8	4.8
		(1.4)	(1.3)	(3.5)	(2.8)	(1.1)	(4.4)	(3.9)	(3.0)	(4.2)	(4.3)	(0.8)	(3.9)
Graminoids	Pre	1.0	1.4	1.2	0.7	0.6	1.6	1.6	3.5	1.2	0.7	1.3	1.4
		(0.4)	(0.8)	(0.6)	(0.3)	(0.2)	(0.6)	(0.6)	(2.6)	(0.6)	(0.4)	(0.8)	(0.4)
	1 year	1.3	1.9	1.2	0.6	1.1	2.6	1.7	1.9	0.9	1.2	1.5	1.7
		(0.6)	(0.9)	(0.4)	(0.2)	(0.5)	(1.3)	(0.6)	(0.9)	(0.3)	(0.8)	(1.0)	(0.9)
	2 year	1.8	0.6	1.4	1.7	0.8	3.9	6.2	2.5	1.8	1.8	2.8	1.9
		(0.9)	(0.2)	(0.4)	(1.1)	(0.3)	(1.6)	(2.8)	(1.2)	(1.1)	(1.1)	(1.5)	(0.9)
Rubus spp.	Pre	2.2	1.7	2.1	2.3	3.6	2.7	4.3	3.0	1.6	4.5	3.6	0.8
		(1.1)	(0.8)	(1.1)	(1.1)	(1.2)	(1.0)	(1.5)	(1.2)	(0.5)	(3.1)	(1.5)	(0.5)
	1 year	**9.5**	**0.1**	0.7	0.7	6.7	4.4	2.7	2.8	3.9	1.0	0.3	0.3
		(3.0)	**(0.1)**	(0.5)	(0.3)	(2.0)	(2.1)	(1.5)	(1.4)	(1.5)	(0.6)	(0.2)	(0.2)
	2 year	**9.2**	1.6	2.9	1.7	**10.2**	5.2	1.6	3.7	**4.9**	1.3	2.9	1.6
		(2.6)	(0.9)	(1.6)	(0.9)	**(4.1)**	(2.0)	(0.7)	(1.5)	**(1.8)**	(0.6)	(1.3)	(0.8)
Other herbaceous	Pre	8.6	6.5	5.2	5.4	5.2	4.1	5.1	5.6	4.9	4.2	6.2	5.9
		(2.7)	(2.2)	(1.4)	(2.1)	(1.3)	(1.3)	(1.1)	(1.5)	(1.1)	(1.1)	(1.6)	(1.5)
	1 year	7.5	3.4	5.2	2.6	7.8	5.4	4.8	4.4	9.7	2.2	4.9	2.8
		(2.2)	(1.0)	(1.5)	(1.2)	(2.5)	(1.5)	(1.2)	(1.7)	(2.6)	(0.6)	(2.2)	(0.9)
	2 year	8.4	6.7	5.9	6.1	11.6	11.9	7.7	8.4	9.8	5.7	5.1	3.9
		(1.9)	(2.2)	(2.0)	(1.8)	(4.8)	(3.7)	(2.3)	(2.9)	(2.6)	(1.8)	(1.6)	(1.5)

and August treatments had cover that ranged from 0.3 to 2.2 percent cover after 2 years. Graminoids (grasses and sedges), Lycopodium species, and flowering plants collectively were all unaffected by sulfometuron methyl at any rate or timing combination (Table 3). Without sulfometuron methyl *Rubus* percent cover significantly increased over time. Various rate and timing combinations reduced *Rubus* cover, though only treatment in July with 2 ounces of sulfometuron methyl per acre differed significantly (Table 3).

Sulfometuron methyl often is used to control ferns when desirable seedlings are present among the fern. The 2-year results of this study showed that very few species were negatively affected by treatment with sulfometuron methyl. One species, downy serviceberry (*Amelanchier arborea*), had lower cover with all rates and times of treatment with sulfometuron methyl (Table 4). The effect was greater later in the season than early in the growing season.

Table 4.—Stem density (thousands of stems per acre) by time and rate of Oust® application. Values in parentheses are standard error of the mean. Numbers are from ten replicates throughout north-central Pennsylvania. Treatments did not differ significantly. Differences from control plots within a treatment month are shown in bold type.

		Thousands of stems per acre found on study plots											
	Year	July (ounces of Oust® /acre)				August (ounces of Oust® /acre)				September (ounces of Oust® /acre)			
		0	2	3	4	0	2	3	4	0	2	3	4
Red maple	Pre	16.4 (4.0)	18.7 (4.7)	24.0 (4.5)	17.6 (3.2)	17.3 (3.0)	15.6 (3.4)	13.2 (3.4)	23.2 (6.2)	20.2 (6.3)	21.3 (5.2)	16.1 (3.4)	15.8 (3.8)
	1 year	14.9 (2.7)	21.6 (5.2)	22.4 (5.2)	18.1 (4.7)	16.5 (3.8)	15.1 (3.7)	16.8 (6.9)	18.7 (4.1)	20.7 (6.9)	24.2 (6.9)	18.4 (4.0)	19.0 (5.8)
	2 year	11.6 (2.7)	16.6 (3.6)	18.9 (3.7)	15.3 (2.8)	11.6 (2.2)	11.8 (2.6)	10.3 (2.8)	15.8 (3.2)	14.6 (4.5)	20.3 (6.2)	15.7 (3.0)	14.8 (4.1)
Sugar maple	Pre	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.2 (0.2)	0.5 (0.3)	0.6 (0.6)	0.1 (0.1)	0.0 (0.0)	0.2 (0.1)	0.3 (0.2)	0.1 (0.1)	0.0 (0.0)
	1 year	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.2 (0.2)	0.4 (0.3)	0.4 (0.3)	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)	0.0 (0.0)	0.2 (0.2)	0.1 (0.1)
	2 year	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.4 (0.3)	0.3 (0.3)	0.1 (0.1)	0.0 (0.0)	0.1 (0.1)	0.3 (0.2)	0.1 (0.1)	0.1 (0.1)
Serviceberry	Pre	3.4 (1.6)	1.3 (0.6)	2.7 (1.1)	1.2 (0.5)	7.2 (3.2)	2.1 (1.0)	2.2 (1.1)	2.2 (0.8)	3.5 (1.6)	3.7 (2.2)	1.7 (0.9)	2.6 (1.5)
	1 year	2.9 (0.9)	**1.2 (0.5)**	**1.3 (1.0)**	**0.7 (0.4)**	4.5 (1.6)	**0.4 (0.3)**	**0.2 (0.1)**	**0.6 (0.2)**	4.3 (1.6)	**0.4** (0.2)	0.2 (0.1)	0.6 (0.6)
	2 year	3.2 (1.2)	**1.2 (0.6)**	**1.7 (0.8)**	**1.2 (0.8)**	5.3 (2.0)	**0.8 (0.3)**	**0.8 (0.3)**	**1.2 (0.5)**	4.2 (1.4)	**0.9 (0.5)**	**0.7 (0.3)**	**1.1 (0.9)**
Black birch	Pre	0.4 (0.2)	0.5 (0.4)	0.2 (0.1)	0.4 (0.2)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.5 (0.3)	0.0 (0.0)	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)
	1 year	0.3 (0.1)	0.3 (0.2)	0.1 (0.1)	0.1 (0.1)	0.0 (0.0)	0.1 (0.1)	0.1 (0.1)	0.2 (0.1)	0.1 (0.1)	0.2 (0.1)	0.1 (0.1)	0.1 (0.1)
	2 year	0.2 (0.1)	0.4 (0.2)	0.1 (0.1)	0.2 (0.1)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.3 (0.3)	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)
American beech	Pre	0.3 (0.2)	0.3 (0.3)	0.1 (0.1)	0.0 (0.0)	0.2 (0.2)	0.2 (0.2)	0.0 (0.0)	0.2 (0.1)	0.0 (0.0)	0.2 (0.1)	0.1 (0.1)	0.2 (0.2)
	1 year	0.4 (0.3)	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)	0.2 (0.2)	0.1 (0.1)	0.0 (0.0)	0.2 (0.2)	0.0 (0.0)	0.3 (0.2)	0.1 (0.1)	0.1 (0.1)
	2 year	0.6 (0.4)	0.2 (0.2)	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.2 (0.1)	0.0 (0.0)	0.2 (0.1)	0.2 (0.2)	0.2 (0.2)

continued

Table 4.—continutted

	Year	Thousands of stems per acre found on study plots											
		July (ounces of Oust® /acre)				August (ounces of Oust® /acre)				September (ounces of Oust® /acre)			
		0	2	3	4	0	2	3	4	0	2	3	4
Yellow-poplar	Pre	0.3 (0.2)	0.9 (0.7)	0.9 (0.6)	0.5 (0.3)	0.4 (0.3)	0.5 (0.3)	1.0 (0.6)	1.1 (0.6)	1.0 (0.9)	1.0 (0.6)	0.6 (0.5)	0.9 (0.9)
	1 year	0.5 (0.3)	0.8 (0.5)	1.1 (0.6)	0.5 (0.4)	0.3 (0.2)	0.4 (0.3)	1.1 (0.6)	0.8 (0.5)	0.6 (0.6)	0.9 (0.5)	0.5 (0.3)	0.7 (0.7)
	2 year	0.4 (0.3)	1.3 (0.9)	1.1 (0.7)	0.6 (0.4)	0.4 (0.3)	0.6 (0.5)	0.9 (0.5)	0.8 (0.4)	0.8 (0.8)	0.9 (0.5)	0.4 (0.2)	0.7 (0.7)
Cucumbertree	Pre	0.4 (0.2)	0.5 (0.3)	0.3 (0.2)	0.5 (0.3)	0.4 (0.2)	0.4 (0.2)	0.6 (0.2)	0.1 (0.1)	0.5 (0.2)	0.6 (0.3)	0.3 (0.2)	0.3 (0.2)
	1 year	0.4 (0.1)	0.5 (0.3)	0.4 (0.2)	0.3 (0.1)	0.4 (0.2)	0.6 (0.3)	0.3 (0.1)	0.1 (0.1)	0.5 (0.2)	0.5 (0.2)	0.2 (0.1)	0.2 (0.1)
	2 year	0.4 (0.2)	0.4 (0.2)	0.3 (0.1)	0.6 (0.2)	0.7 (0.5)	0.3 (0.2)	0.6 (0.2)	0.1 (0.1)	0.6 (0.2)	0.3 (0.1)	0.2 (0.1)	0.2 (0.1)
Pin cherry	Pre	0.2 (0.2)	0.3 (0.2)	0.2 (0.1)	0.3 (0.2)	0.1 (0.1)	0.1 (0.1)	0.1 (0.1)	0.2 (0.2)	0.1 (0.1)	0.0 (0.0)	0.2 (0.2)	0.0 (0.0)
	1 year	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.2 (0.1)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
	2 year	0.2 (0.2)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.0 (0.0)	0.0 (0.0)
Black cherry	Pre	2.9 (1.2)	3.3 (1.2)	5.8 (3.0)	2.4 (0.8)	8.1 (3.8)	10.6 (6.9)	11.0 (6.0)	10.0 (5.4)	5.4 (1.9)	9.7 (5.0)	7.5 (3.3)	6.6 (4.1)
	1 year	2.3 (0.8)	2.0 (1.0)	2.8 (1.2)	1.4 (0.5)	6.4 (2.5)	5.3 (3.1)	4.6 (2.2)	4.3 (2.0)	4.9 (1.5)	5.4 (2.7)	6.9 (3.1)	2.9 (1.8)
	2 year	1.6 (0.6)	2.2 (0.9)	3.3 (1.2)	1.4 (0.5)	4.8 (1.5)	4.2 (2.0)	4.6 (2.2)	4.4 (2.2)	2.8 (0.8)	4.5 (2.7)	4.4 (1.6)	2.2 (1.3)
Red oak	Pre	5.0 (1.4)	5.2 (1.6)	6.3 (2.0)	6.7 (2.0)	6.6 (2.1)	4.7 (1.2)	5.5 (1.9)	6.8 (2.0)	7.5 (2.6)	4.5 (1.5)	5.8 (2.3)	8.4 (5.2)
	1 year	5.2 (1.3)	6.1 (1.7)	7.8 (2.2)	6.1 (1.5)	5.9 (2.2)	4.8 (1.4)	4.8 (1.5)	5.2 (1.4)	6.2 (2.3)	5.1 (1.9)	6.3 (2.0)	7.2 (3.4)
	2 year	4.5 (1.4)	5.9 (1.7)	8.2 (2.3)	5.7 (1.5)	5.7 (2.1)	4.7 (1.4)	4.3 (1.4)	5.2 (1.4)	6.3 (2.2)	5.3 (1.6)	7.2 (2.3)	6.7 (3.2)

SUMMARY OF ALL STUDIES

Herbicides remain an important tool in the regeneration toolbox that landowners have at their disposal. Several years of changing product labeling on glyphosate products resulted in varying surfactants being used without research guidance. Striped maple have grown into larger size classes since initial research was conducted on the Allegheny Plateau, and treatment of the entire crown with chemicals has become more difficult. Surfactants and altered rates and timing of herbicide application for striped maple control have also had mixed results. Managers began adding imazapyr in hopes of improving striped maple control. Use of imazapyr is not detrimental to seedling development and does not improve taller striped maple control. The results presented here show that Roundup PROMAX® herbicide, including its proprietary surfactant, achieves the best control of all striped maple.

Sulfometuron methyl, or Oust® XP herbicide, controls ferns effectively. Past research suggested the later the treatment the better, but the results shown here suggest that July or August application with 2 or 3 ounces of product per acre controls ferns best and results in less regrowth. Nontargeted species and tree species are not affected except for serviceberry, which was reduced by sulfometuron methyl application. All sulfometuron methyl applications with a goal of protecting seedlings should not use a surfactant. Early work done showed that use of a surfactant in the mix with sulfometuron methyl damaged most hardwood species. Oust® is still an effective tool.

Silvicultural use of herbicides as part of the regeneration process continues to control unwanted vegetation and thus reduce low shade on developing seedlings. This research provides expanded guidance on when to use the tools most effectively and is applicable in Pennsylvania and other states (Brose et al. 2008, Marquis 1994, Marquis et al. 1992).

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APPENDIX: Statistical Methods

Imazapyr Study

SAS version 9.4 (SAS Institute Inc. 2011) was used for all statistical analyses. Generalized linear mixed models using PROC MIXED were used to model the effects of year, site, rate, and timing of herbicide application on target variables. In all models, site was considered a random effect; year, rate, and timing were fixed effects. Year was considered a repeated measure (Littell et al. 2006). All models used the restricted maximum-likelihood (REML) method and the Kenward-Roger procedure to adjust the denominator degrees of freedom (SAS Institute 2011). Tukey-Kramer tests in the LSMEANS option of the MIXED procedure were used to conduct post-hoc tests to identify years with significant differences between control and experimental treatments.

Surfactant Study

Generalized linear mixed models using PROC MIXED were used to model the effects of site and surfactant used with herbicide application on target variables. In all models, site was considered a random effect; surfactant was a fixed effect. Year was considered a repeated measure (Littell et al. 2006). All models used the REML method and the Kenward-Roger procedure to adjust the denominator degrees of freedom (SAS Institute 2011). Tukey-Kramer tests in the LSMEANS option of the MIXED procedure were used to conduct post-hoc tests to identify differences between treatments.

Revisiting the Oust® Prescription

Generalized linear mixed models using PROC MIXED were used to model the effects of year, site, rate, and timing of herbicide application on target variables. In all models, site was considered a random effect; year, rate, and timing were fixed effects. Year was considered a repeated measure (Littell et al. 2006). All models used the REML method and the Kenward-Roger procedure to adjust the denominator degrees of freedom (SAS Institute 2011). Tukey-Kramer tests in the LSMEANS option of the MIXED procedure were used to conduct post-hoc tests to identify years with significant differences between control and experimental treatments.

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