United States Department of Agriculture

Forest Service

Northern Research Station

Research Paper NRS-21

A Comparison of Two Stem Injection Treatments Applied to American Beech in Central West Virginia

Jeffrey D. Kochenderfer
Gary W. Miller
James N. Kochenderfer

Abstract

Efficacies for two herbicide stem injection treatments on American beech (*Fagus grandifolia* Ehrh.) and impacts to nontarget residual trees were evaluated in central West Virginia. The treatments consisted of hack-and-squirt injection of all beech stems ≥1.0 in. to 9.9 in. diameter at breast height (d.b.h.) with either imazapyr as Arsenal™ (28.7 percent) or glyphosate as Razor Pro™ (41 percent) in water carriers. The treatments were applied in September 2008 and evaluated 12 months after treatment. Complete control of injected stems was achieved with both treatments; however, treatment efficacy on untreated beech stems >1.0 ft tall to 0.9 in. d.b.h. was higher on the Arsenal treatments. No damage occurred to any desirable overstory species such as black cherry (*Prunus serotina* Ehrh.) or red maple (*Acer rubrum* L.) trees that were located on all the treatment plots. Land managers can use the hack-and-squirt injection treatments described in this study to control both injected trees and a large proportion of smaller beech root sprouts associated with them.

Cover Photo

Injecting an American beech using a hatchet with a 1.75-inch-wide bit and spray bottle containing a 50 percent solution of Razor Pro™ herbicide in a water carrier. Photo by James N. Kochenderfer, U.S. Forest Service (retired).

Manuscript received for publication 23 November 2011

Published by:

U.S. FOREST SERVICE
11 CAMPUS BLVD SUITE 200
NEWTOWN SQUARE PA 19073

September 2012

For additional copies:

U.S. Forest Service
Publications Distribution
359 Main Road
Delaware, OH 43015-8640
Fax: (740)368-0152
Email: nrspubs@fs.fed.us

Visit our homepage at: **http://www.nrs.fs.fed.us/**

INTRODUCTION

Timber harvesting in the central Appalachians in the decades following heavy cutting in the early 20th century has usually involved some type of partial cutting that encourages the development of shade-tolerant species (Trimble 1973). Dense understories of tolerant species also develop naturally in Appalachian stands that have not been disturbed for many years. Once established, these tolerant understories can respond rapidly to additional overstory cutting, further increasing shade that can lead to a site conversion to shade-tolerant species (Nyland et al. 2006a). Research studies have demonstrated that dense understories of shade-tolerant species such as American beech (*Fagus grandifolia* Ehrh.) and striped maple (*Acer pensylvanicum* L.) can interfere with the establishment and development of desirable shade-intolerant reproduction (Horsley and Bjorkbom 1983, Miller et al. 2004, Nyland et al. 2006b).

Stem injection herbicide treatments of undesirable understory vegetation to facilitate regeneration of desirable species have been recommended for Appalachian hardwood stands. Loftis (1990) described a shelterwood method for regenerating northern red oak (*Quercus rubra* L.) in the southern Appalachians. It includes retention of the main canopy and stem injection of subcanopy stems ≥0.6 in. diameter at breast height (d.b.h.) to provide proper light conditions for promoting development of existing red oak regeneration while controlling competition from resprouting and fast growing intolerant trees. Stem injection herbicide treatments are also recommended in the mid-Atlantic mixed oak forests and Allegheny hardwood stands to control understory vegetation where mechanical broadcast spraying treatments might not be feasible or desirable (Brose et al. 2008, Marquis et al. 1992, Miller et al. 2004). These understory herbicide treatments are expected to provide at least a 10-year period in which competition will be controlled enough to permit desirable regeneration to become competitive before final overstory removal harvests.

Studies in central West Virginia have found that most advance beech reproduction originates from root sprouts (Kochenderfer et al. 2004, 2006). Dense thickets of beech root sprouts often develop following mortality of trees affected by beech bark disease (Houston 1975, Ostrofsky and McCormack 1986). Simply cutting beech stems > 6.0 in. d.b.h. in central West Virginia almost doubled the number of live beech root sprouts (Kochenderfer et al. 2006). The ability of this very shade-tolerant species to regenerate vegetatively by root sprouts

The Authors

JEFFREY D. KOCHENDERFER is a forester with the U.S. Forest Service's Monongahela National Forest at Petersburg, WV.

GARY W. MILLER is a research forester with the U.S. Forest Service's Northern Research Station at Morgantown, WV.

JAMES N. KOCHENDERFER is a retired research forester with the U.S. Forest Service's Northern Research Station at Parsons, WV.

gives beech a competitive advantage in an understory environment over other species that must depend on seed to regenerate. Leak (2009) attributed beech aggressiveness to its suckering capability in New Hampshire where he found that after 70 years of understory development beech had increased in almost every elevation zone up to 2,700 ft. Beech is more competitive under partial cutting regimes and is very resilient to deer browsing (Horsley et al. 2003, Tubbs and Houston 1990).

Hack-and-squirt stem injection is usually considered one of the least expensive manual herbicide application methods. When used properly, it is a target-specific treatment that can be used on stems ≥1.0 in. d.b.h., on steep topography, and on small ownerships where mechanical broadcast spraying might not be feasible. It can control interference without impacting advance regeneration or desirable residual stems. Another advantage of using the stem injection application method is that when root sprouting species are injected with water soluble herbicides containing the active ingredients glyphosate or imazapyr, a large proportion of attached root sprouts will also be controlled. This advantage is important because it can be very costly to treat large numbers of individual stems with herbicide (Zedaker 1986). A study in central West Virginia indicated that in addition to controlling all beech stems ≥6.0 in. d.b.h. injected with a 50-percent solution of glyphosate as Accord™ (41.5 percent), this treatment also controlled 52 percent and 21.6 percent of small untreated beech understory stems in the 2-ft tall to 0.9- in. d.b.h. class and the 1.0- to 5.9- in. d.b.h. class, respectively (Kochenderfer et al. 2004). In another study in the same area, efficacy was determined for hack-and-squirt injection treatments on striped maple using 6- and 9-percent solutions of imazapyr as Arsenal™ (28.7 percent) and 50- and 100-percent solutions of glyphosate as Glypro Plus™ (41.0 percent) in water carriers (Kochenderfer and Kochenderfer 2008). Complete control of injected stems was achieved with all treatments; however, the Arsenal™ treatments resulted in greater control of basal sprouting, untreated striped maple stems, and sprout clumps. Because Arsenal™ (imazapyr), unlike Glypro Plus™ (glyphosate), has soil activity, there was some concern in that study about damage to nontarget black cherry (*Prunus serotina* Ehrh.) crop trees located on 66 percent of the research plots; however, only one black cherry crop tree was slightly damaged where a 9-percent solution of Arsenal™ was used. In an earlier study, a much higher concentration of imazapyr caused damage to some crop trees when treated trees were the same species as the crop trees (Kochenderfer et al. 2001). In this study a much lower concentration of imazapyr was used and the treated trees and crop trees were different species.

Those previous study results gave us the impetus to further evaluate stem injection treatments on American beech. Because American beech is one of the most widespread interfering plants in Appalachian forests, it is important to give land managers information that will enable them to choose the most cost effective stem injection treatment they can use to control beech without damaging desirable stems. The objective of this study was to compare the efficacy of stem injection treatments using glyphosate as Razor Pro™ (41.0 percent) and imazapyr as Arsenal™ (28.7 percent) on injected trees and their associated root sprouts, and on nontarget overstory residual trees.

METHODS

Study Area

The study was installed in a northern hardwood stand at an elevation of 3,600 ft in central West Virginia near the town of Davis on property managed by Western Pocahontas Properties. American beech, black cherry, and red maple were the most common overstory trees at the study site; beech root sprouts and striped maple were the most prevalent interfering understory plants. Past partial harvests (the last one occurring about 30 years ago), beech bark disease, and preferential deer browsing have resulted in the development of a dense understory of beech root sprouts on much of the study area.

Size distribution of stems and basal area for the stand are shown in Table 1. Most of the stems (89 percent) are small beech stems <1.0 in. d.b.h., but 87 percent of stand basal area is in trees 6.0 in. d.b.h. and larger. Total stand basal area in trees >1.0 in. d.b.h. averaged 165.8 ft^2/ac. Beech represented 51 percent of the total stand

Table 1.—Average initial number of stems and basal area for the study site

Size Class (inches d.b.h.)		Stems (number/ac)	Basal Area (ft^2/ac)
<1.0	Beech	5,767	------
	Other	------	------
1.0-5.9	Beech	405	20.85
	Black Cherry	------	-------
	Red Maple	3	0.17
	Sugar Maple	8	0.49
	Striped Maple	45	0.47
6.0-11.0	Beech	167	58.72
	Black Cherry	17	8.41
	Red Maple	12	5.24
	Sugar Maple	7	2.53
	Striped Maple	------	-------
>11.0	Beech	7	4.86
	Black Cherry	45	47.02
	Red Maple	15	15.93
	Sugar Maple	2	1.14
	Striped Maple	-------	--------
Total: Beech		6,346	84.43
Black Cherry		62	55.43
Red Maple		30	21.34
Sugar Maple		17	4.16
Striped Maple		45	0.47
All species		6,500	165.83

basal area at the study site. Most of the beech basal area (70 percent) was concentrated in the 6.0- to 11.0-in. size class. Basal area in the "other" species category (Table 1) averaged 81.4 ft^2/ac; black cherry (55.4 ft^2/ac) and red maple (21.3 ft^2/ac) were the two most dominant species in this category. Most of the residual basal area (77.3 percent) on the treated plots was composed of sawtimber-size black cherry and red maple.

DESIGN AND TREATMENTS

Twelve 0.05-ac circular treatment plots were located on the study site. Plots were located where numerous beech stems ranging from 1.0 ft tall to 12.6 in. d.b.h. were present and at least one black cherry overstory tree >11.0 d.b.h. that could be evaluated for collateral herbicide damage. A circular 0.01-ac plot located around each 0.05-ac circular plot center was required to contain at least 20 beech stems in the 1.0-ft tall to 0.9-in. d.b.h. size class. A 50-ft untreated buffer was left between plots. All trees ≥1.0 in. d.b.h. were tagged on the 0.05-ac plots. Standing dead beech stems were removed from the plots. D.b.h. and species were recorded for each stem ≥1.0 in. d.b.h., and beech stems ≥1.0 in. to 9.9 in. d.b.h. were flagged and the number of required incisions (one incision per inch of d.b.h.) was written on each flag. A 0.01-ac circular plot was established around each treatment plot center to determine treatment efficacy on untreated beech stems < 1.0 in. d.b.h. All beech stems 1.0 ft tall to 0.9 in. d.b.h. were tagged on the 0.01-ac plots. Stem counts were recorded for the 1.0-ft tall to 6.0-ft tall and 6.0-ft tall to 0.9-in. d.b.h. size classes. Beech root sprouts originating from the same point were counted as one stem following procedures recommended for counting woody interference by Marquis et al. (1992).

Two herbicide injection treatments and one control treatment were randomly assigned to the 12 plots. Each treatment was replicated four times. The hack-and-squirt injection method was used to apply the herbicide treatments. The two herbicides used in the injection treatments were isopropylamine salt of imazapyr as Arsenal™ (28.7 percent) and glyphosate N-(phosphonomethyl) glycine as Razor Pro™ (41 percent) in water carriers. The three treatments included the following concentrations of formulated product: Arsenal™ (6 percent), Razor Pro™ (50 percent), and Control (no treatment). Instructions for mixing the proper concentration of herbicide were described in Kochenderfer et al. (2012). The two injection treatments were applied to all beech stems ≥1.0 in. to 9.9 in. d.b.h. in September 2008 using two applicators; beech stems larger than 9.9 in. d.b.h. were not treated. One incision per inch of d.b.h. was applied using a hatchet with a ground-down bit 1.75 in. wide. A plastic spray bottle calibrated to dispense 0.9 ml per squirt was used to apply approximately 1.5 ml of solution into each incision. The actual volume of herbicide used for each herbicide application was recorded for each treatment plot.

EFFICACY EVALUATIONS

The plots were evaluated in September 2009, 12 months after treatment. A numerical rating system based on visual estimation of crown control ranging from 1 to 7 (0-100 percent crown affected) was used to evaluate the efficacy of each treatment on both targeted and nontargeted individual stems (Kochenderfer et al. 2001, Memmer and Maass 1979). Two observers rated all stems on each plot. The main ratings for each plot showed no discernible bias among observers, so ratings were not adjusted. Stems with an efficacy rating of 5.0 or higher (75 percent crown necrotic) were considered controlled. All the tagged beech stems from ≥1.0 ft tall to 9.9 in. d.b.h. in the study were used to determine the efficacy of the stem injection treatments. All the tagged stems on the four plots in each treatment were lumped together for statistical analysis. The relationship between the three treatments and percentage of stems controlled by size class was analyzed using a one-way analysis of variance (Sall et al. 2001).

A procedure used by Kochenderfer et al. (2001) was modified to determine treatment cost-effectiveness ($/stem controlled). Total treatment costs and total number of beech stems controlled per acre were used as variables to compute the cost effectiveness of each herbicide treatment. Actual treatment costs were not collected in this study. Total costs were determined by applying the $0.028 per inch of d.b.h. treatment cost determined by Kochenderfer et al. (2004) from injection treatments in a similar stand near this study area to the total inches of d.b.h. treated per acre in this study. Lower cost effectiveness reflects the most efficient treatments. The cost effectiveness of both herbicide injection treatments was determined using the following formula:
CE= TC/TSC
Where

Cost effectiveness (CE) = Average cost to control each beech stem.
Total treatment costs (TC) = Total costs include labor ($10/hr) and chemical costs
Total stems controlled (TSC) = Average number of stems controlled per acre.

RESULTS AND DISCUSSION

Injection application and cost data are shown in Table 2. Thirty-two percent more basal area was treated in the Razor Pro™ treatment. Average treated stem diameter was 1.0 in. larger and 65 more stems per acre were treated on the Razor Pro™ plots. The amount of herbicide applied per incision was lower than intended on the Arsenal™ plots; it averaged 1.2 ml and 1.5 ml for the Arsenal™ and Razor Pro™ treatments, respectively. The larger volume of herbicide applied per incision, coupled with the large number of incisions, resulted in more herbicide being applied on the Razor Pro™ plots. There were six untreated stems controlled for each stem injected on the Razor Pro™ plots compared to nine stems on the Arsenal™ plots. The average number of untreated beech stems controlled per treated stem was 33 percent higher on the Arsenal™ plots. This finding is reflected in the cost effectiveness values shown in Table 2 for the two treatments. It cost almost twice as much to control each stem on the Razor Pro™ plots (Table 2). Average cost effectiveness was 43 percent more favorable on the Arsenal™ treatment because the total inches of d.b.h. treated per acre was 30 percent lower and a higher percentage of untreated stems were controlled on the Arsenal™ plots, which reduced treatment costs.

Table 2.—Injection application data and treatment cost

Characteristic	Arsenal 6%	Razor Pro 50%
Basal area treated (ft^2/ac)	62.22	91.60
Average number of beech stems treated (number/ac)	495	560
Average d.b.h. (in.)	3.8	4.8
Amount of herbicide used (gal/ac)	0.62	1.08
Application cost ($/ac)*	52.67	75.26
Average number of untreated stems controlled per treated stem	9	6
Cost effectiveness ($/stem controlled)	0.012	0.021

*Based on $0.028 per inch of d.b.h. treated.

Table 3.—Initial number of beech stems/acre and percentage of stems controlled by each treatment, by size class

Treatment	Size Class: 1.0 ft tall to 6.0 ft tall		Size Class: >6.0 ft tall to 0.9 in. d.b.h		Size Class: 1.0 to 9.9 in. d.b.h.	
	Initial beech stems	Beech stems controlled* (%)	Initial beech stems	Beech stems controlled* (%)	Initial beech stems	Beech stems controlled* (%)
6% Arsenal	4,250	83a	1,475	63a	495	100a
50% Razor Pro	5,000	66a	1,150	56a	560	100a
Control	3,550	1b	1,875	1b	630	5b

*means followed by the same letter are not significantly different at the .01 level (Experimentwise) using Tukey's HSD.

The reductions in stand basal area associated with each treatment are shown in Figure 1. Before treatment stand basal area averaged 159.1 ft^2/ac and 181.1 ft^2/ac on the Arsenal™ and Razor Pro™ plots, respectively. Beech basal area averaged 76.9 ft^2/ac on the Arsenal™ plots and 102.2 ft^2/ac on the Razor Pro™ plots. There were 62.2 ft^2/ac of beech basal area controlled on the Arsenal plots compared to 91.6 ft^2/ac on the Razor Pro™ plots. After treatment, residual stand basal area was similar on the treated plots. Untreated basal area in beech trees >9.9 in. d.b.h. was slightly higher on the Arsenal™ plots (14.64 ft^2/ac versus 11.23 ft^2/ac) than on the Razor Pro™ plots.

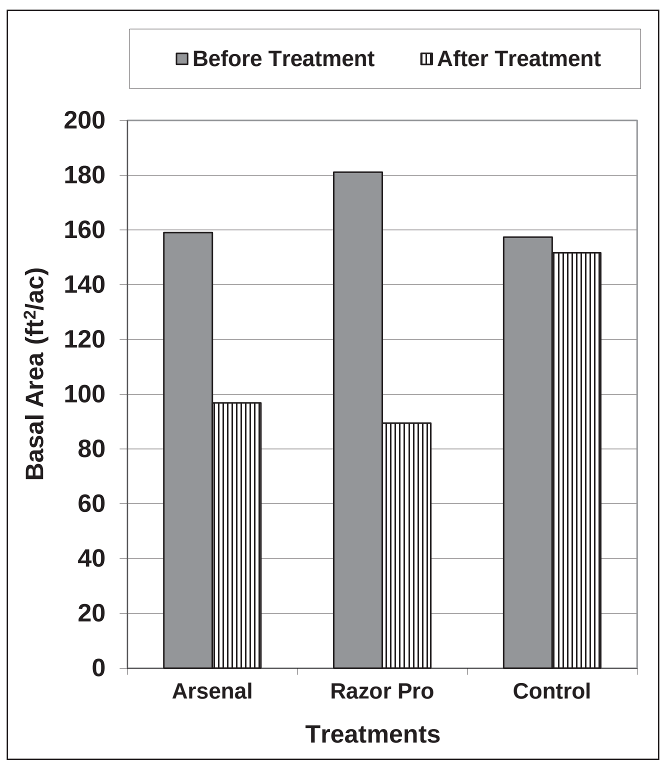

Figure 1.—Average stand basal area (ft^2/ac) before and after the injection treatments; American beech basal area was reduced by 87 percent on the treated plots.

Treatment efficacy is shown in Table 3. Both treatments were effective in controlling beech root sprouts (Fig. 2). Overall, the Arsenal™ and Razor Pro™ treatments controlled 77 percent and 64 percent of all the untreated beech stems 1.0 ft tall to 0.9 in. d.b.h., respectively. The Arsenal™ treatment controlled 83 percent and the Razor Pro™ controlled 66 percent of the 1.0-ft-tall to 6.0-ft-tall untreated beech root sprouts. Control of untreated beech in the >6.0-ft-tall to 0.9-in. d.b.h. class was much closer,

Figure 2.—Root sprout efficacy after 3 years on a study plot treated with a 6-percent solution of Arsenal™ in a water carrier.

63 percent and 56 percent for the Arsenal™ and Razor Pro™ treatments, respectively. Both treatments controlled 100 percent of the treated stems and were significantly more effective than on the untreated plots; control (natural mortality) averaged only 1 percent for all size classes (Fig. 3). These results are consistent with other studies that have used glyphosate to control American beech (Kochenderfer et al. 2001, 2004). The higher overall efficacy of 77 percent for untreated stems on the Arsenal™ treatment compares favorably with the average efficacy (85 percent) observed on a beech cut-stump study in the same area (Kochenderfer and Kochenderfer 2009). Although the Arsenal™ treatment controlled 13 percent more of the untreated beech stems, there was no statistical significant difference between the two treatments (Table 3). The lack of statistical significance can probably be attributed to the wide variation in efficacy on untreated beech stems among individual plots within treatments, particularly within the Razor Pro™ treatment where efficacy within plots ranged from 39 to 90 percent as opposed to the Arsenal™ plots where efficacy within plots ranged from 74 to 80 percent. There was only a 10-percent difference in the mean treatment efficacy for the untreated stems when the plot with the lowest efficacy in each treatment was eliminated in the analysis.

The reduced efficacy on some of the Razor Pro™ plots is not fully understood but could be attributed to a number of factors. First, there is the natural inherent variability in the distribution of treated and untreated beech stems on the plots. Cut-stump studies have clearly demonstrated that beech root sprout mortality is not uniform but was higher close to the treated stumps and around larger beech stumps treated with glyphosate (Kochenderfer et al. 2006). In another cut-stump study in a northern hardwood stand in West Virginia where Kochenderfer and Kochenderfer (2009) studied cut-stump treatments, efficacy was not clearly related to distribution of treated stumps within the plots. Plots with fewer widely spaced cut stumps did not always have a corresponding lower efficacy. Kochenderfer and Kochenderfer (2009) pointed out that efficacy would not be affected in areas that had no root sprouts and that root grafts between treated tree stumps and root sprouts from other trees might extend treatment effects.

Figure 3.—An untreated control plot showing the dense understory of beech root sprouts.

Another factor that could have influenced plot efficacy was the amount of basal area treated. When herbicides are applied to plants, they migrate to the most active growing parts of the plants, i.e., the cambium and buds, where they exert toxicity within the plant (Anderson 1996). Unlike cut-stump treatments where all the applied herbicide is potentiality available to be translocated to attached root sprouts or through root grafts to other stems, much of the injected herbicide is tied up by the injected trees themselves and unavailable to be translocated to other stems. Because the treated stems were larger and more numerous on the Razor Pro™ plots, more of the herbicide could have been tied up in these larger stems and less herbicide would have been available to control attached root sprouts.

Black cherry crop trees occurred on 100 percent of the plots. A total of 13 black cherry crop trees were located on the Razor Pro™ plots and 8 were located on the Arsenal™ plots. None of the black cherry crop trees were damaged by either of the herbicide treatments. In addition, 15 red maples located on the treated plots were not damaged by the herbicide treatments. Imazapyr, the active ingredient in Arsenal™, is soil active (Anderson 1996) and can be absorbed through the roots of untargeted plants (USDA 1989). Past studies using Arsenal™ have shown some damage to untreated black cherry crop trees (Kochenderfer et al. 2001, Kochenderfer and Kochenderfer 2008). The lack of damage in this study can probably be attributed to the lower concentrations of Arsenal™ used, 6 percent compared to 9 and 15 percent used in those studies, and restricting treatment to only beech stems precluded transmission to other species by root grafts because interspecific grafts between roots of different species are rare (Graham and Bormann 1966). Damage to black cherry crop trees was not expected on the Razor Pro™ plots because glyphosate, the active ingredient in Razor Pro™, has no soil activity and can move to other trees only through root grafts.

Some unintended damage was observed on beech trees greater than 9.9 in. d.b.h. with both herbicide treatments. A total of 10 beech trees larger than 9.9 in. d.b.h. were located on the treated plots. One beech tree in the Arsenal™ treatment was killed and one tree in the Razor Pro™ treatment was damaged. Although there were not enough beech trees larger than 9.9 in. d.b.h. to draw statistical inferences, these results demonstrate that herbicide injected into smaller treated stems can move to the larger untreated stems of the same species, probably via root grafts, and cause damage. Kochenderfer et al. (2006) observed that larger residual beech trees near beech stumps that had been treated with a 100-percent solution of Glypro™ (53.8 percent) herbicide seemed to function as pumps and created gradients that drew herbicide to them, controlling the large uncut beech trees as well as smaller beech root sprouts associated with them.

MANAGEMENT IMPLICATIONS

This study demonstrated that hack-and-squirt injection treatments using a 6-percent solution of Arsenal™, which is equivalent to a 3-percent solution of Arsenal™ AC, or a 50-percent solution of Razor Pro™ herbicides in water carriers are effective treatments when applied to beech stems 1.0 in. to 9.9 in. d.b.h., which will control both injected trees and a large proportion of small beech root sprouts associated with them. Both herbicide treatments used in this study were effective.

Damage to residual trees was minimal in this study, but because Arsenal™ has soil activity, Arsenal™ treatments have a greater potential to damage nontarget stems than the Razor Pro™ treatments. Using low herbicide concentrations and application rates like those used in this study and restricting treatment to species different from those considered desirable for crop trees will minimize damage to desirable species. The use of these injection treatments is not recommended during periods of sap flow that frequently occur between November 1 and leaf out in this region of the Appalachians. When stands contain an undesirable striped maple component in the understory, the Arsenal™ treatment would be preferred because research has shown Arsenal™ is more effective on maple (*Acer* spp.) than glyphosate treatments (Kochenderfer and Kochenderfer 2008).

Other studies have shown that the cut-stump treatment will control a larger proportion of untreated beech root sprouts than stem injection treatments; however, the use of the cut-stump treatment is restricted to stands where enough freshly cut beech stumps are available for treatment (Kochenderfer et al. 2006). The hack-and-squirt treatments described in this study are more versatile than cut-stump treatments over a wide range of stand conditions to accomplish different silvicultural objectives. For example, injection treatments can be applied where previous harvests or beech bark disease has eliminated the larger beech trees, thus leaving few treatable stumps to control the undesirable beech sprouts that remain. Injection treatments can also be used before timber harvests to control dense understories that interfere with the development of advance reproduction of desirable species. The injection treatments described in this study and cut-stump treatments are especially applicable on root sprouting species like beech, where several stems can be controlled by treating one stem or stump. This study provides land managers with useful information that will enable them to select stem injection treatments with high efficacies that fit their stand conditions and silviculture objectives when attempting to control American beech in Appalachian forest stands.

ACKNOWLEDGMENTS

The authors thank Douglas N. Toothman, Western Pochahontas Properties, for providing the study site. The authors thank John Stanovick, statistician with the Northern Research Station, for assistance with the statistical analyses, and Arlyn Perkey, David McGill, and Todd Ristau for technical review comments.

LITERATURE CITED

Anderson, W.P. 1996. **Weed science principles and applications.** 3rd ed. St. Paul, MN: West Publishing Company. 398 p.

Brose, P.H.; Gottschalk, K.W.; Horsley, S.B; Knopp, P.D.; Kochenderfer, J.N.; McGuinness, B.J.; Miller, G.W.; Ristau, T. E.; Stoleson, S. H.; Stout, S.L. 2008. **Prescribing regeneration treatments for mixed-oak forests in the Mid-Atlantic region.** Gen. Tech. Rep. NRS-33. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 90 p.

Graham, B.F., Jr.; Bormann, F.H. 1966. **Natural root grafts.** Botanical Review. 32: 255-292.

Horsley, S.B.; Bjorkbom, J.C. 1983. **Herbicide treatment of striped maple and beech in Allegheny hardwood stands.** Forest Science. 29(1): 103-112.

Horsley, S.B.; Stout S.L.; DeCalesta, D.S. 2003. **White-tailed deer impact of the vegetation dynamics of a northern hardwood forest.** Ecological Applications. 13(1): 98-118.

Houston, D.R. 1975. **Beech bark disease: the aftermath forests are structured for a new outbreak.** Journal of Forestry. 73(10): 660-663.

Kochenderfer, J.D.; Kochenderfer, J.N. 2008. **Efficacy of stem injection treatments on striped maple in central West Virginia.** Field Note. Northern Journal of Applied Forestry. 25(2): 106-108.

Kochenderfer, J.D.; Kochenderfer, J.N. 2009. **Effects of herbicide concentration and application timing on the control of beech root and stump sprouts using the cut-stump treatment.** Gen Tech. Rep. NRS-48. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 10 p.

Kochenderfer, J.D.; Kochenderfer, J.N.; Miller, G.W. 2006. **Controlling beech root and stump sprouts using the cut-stump treatment.** Northern Journal of Applied Forestry. 23(3): 155-165.

Kochenderfer, J.D.; Kochenderfer, J.N.; Miller, G.W. 2012. **Manual herbicide application methods for managing vegetation in Appalachian hardwood forests.** Gen. Tech. Rep. NRS-96. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 59 p.

Kochenderfer, J.D.; Kochenderfer, J.N.; Warner, D.A.; Miller, G.W. 2004. **Preharvest manual herbicide treatments for controlling American beech in central West Virginia.** Northern Journal of Applied Forestry. 21(1): 40-49.

Kochenderfer, J.D.; Zedaker, S.M.; Johnson, J.E.; Smith, D.W.; Miller, G.W. 2001. **Herbicide hardwood crop tree release in central West Virginia.** Northern Journal of Applied Forestry. 18(2): 46-54.

Leak, W.B. 2009. **Seventy years of understory development by elevation class in a New Hampshire mixed forest: management implications.** Field Note. Northern Journal of Applied Forestry. 26(4):164-166.

Loftis, D.L. 1990. **A shelterwood method for regenerating red oak in the southern Appalachians.** Forest Science. 36(4): 917-929.

Marquis D.A.; Ernst, R.L.; Stout, S.L. 1992. **Prescribing silvicultural treatments in hardwood stands of the Alleghenies (revised).** Gen. Tech. Rep. NE-96. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 101 p.

Memmer, P.; Maass, D. 1979. **Results of tree injection treatments in Monson, Maine.** In: Proceedings of the Northeastern Weed Science Society; 1979 January 3-5; Boston, MA. Northeastern Weed Science Society. Vol. 33, Supplement: 50-51.

Miller, G.W.; Kochenderfer, J.N.; Gottschalk, K.W. 2004. **Effect of pre-harvest shade control and fencing on northern red oak seedling development in the central Appalachians.** In: Spetich, M.A., ed. Upland oak ecology symposium: history, current conditions, and sustainability. Gen. Tech. Rep. SRS-73. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 182-189.

Nyland, R.D.; Bashant, A.L.; Bohn, K.K.; Verostek, J.M. 2006a. **Interference to hardwood regeneration in northeastern North America: ecologic characteristics of American beech, striped maple, and hobblebush.** Northern Journal of Applied Forestry. 23(1): 53-61.

Nyland, R.D.; Bashant, A.L.; Bohn, K.K.; Verostek, J.M. 2006b. **Interference to hardwood regeneration in northeastern North America: controlling effects of American beech, striped maple, and hobblebush.** Northern Journal of Applied Forestry. 23(2): 122-132.

Ostrofsky, W.D.; McCormack, M.L., Jr. 1986. **Silvicultural management of beech and the beech bark disease.** Northern Journal of Applied Forestry. 3(3): 89-91.

Sall, J.; Lehman, A.; Creighton, L. 2001. **JMP Start Statistics.** 2d ed. Cary, NC: SAS Institute Inc: 171-185.

Trimble, G.R., Jr. 1973. **The regeneration of central Appalachian hardwoods with emphasis on the effects of site quality and harvesting practice.** Res. Pap. NE-282. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 14 p.

Tubbs, C.H.; Houston, D.R. 1990. **American beech (*Fagus grandifolia* Ehrh.).** In: Burns, R.M.; Honkala, B.H., eds. Silvics of North America Agric. Handb. 654. Vol. 2. Washington DC: U.S. Department of Agriculture: 325-332.

USDA Forest Service. 1989. **Vegetation management in the Appalachian Mountains.** Vol 1. Manage. Bull. R8-MB38. 399 p.

Zedaker, S.M. 1986. **Herbicides and application techniques for managing immature hardwoods.** In: Smith, H.C.; Eye, M.C., eds. Proceedings: Guidelines for managing immature Appalachian hardwood stands. SAF Publ. 86-02. Bethesda, MD: Society of American Foresters: 240-250.

Kochenderfer, Jeffrey D.; Miller, Gary W.; Kochenderfer, James N. 2012. **A comparison of two stem injection treatments applied to American beech in central West Virginia.** Res. Pap. NRS-21. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 10 p.

Efficacies for two herbicide stem injection treatments on American beech (*Fagus grandifolia* Ehrh.) and impacts to nontarget residual trees were evaluated in central West Virginia. The treatments consisted of hack-and-squirt injection of all beech stems ≥1.0 in. to 9.9 in. diameter at breast height (d.b.h.) with either imazapyr as Arsenal™ (28.7 percent) or glyphosate as Razor Pro™ (41 percent) in water carriers. The treatments were applied in September 2008 and evaluated 12 months after treatment. Complete control of injected stems was achieved with both treatments; however, treatment efficacy on untreated beech stems >1.0 ft tall to 0.9 in. d.b.h. was higher on the Arsenal treatments. No damage occurred to any desirable overstory species such as black cherry (*Prunus serotina* Ehrh.) or red maple (*Acer rubrum* L.) trees that were located on all the treatment plots. Land managers can use the hack-and-squirt injection treatments described in this study to control both injected trees and a large proportion of smaller beech root sprouts associated with them.

KEY WORDS: herbicide, American beech, stem injection treatments, efficacy, nontarget residual trees, imazapyr, glyphosate, silviculture

Northern Research Station

www.nrs.fs.fed.us