Extending the Time Interval for Applying Herbicide in Cut-Stump Treatments on American Beech

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

ABSTRACT

American Beech (*Fagus grandifolia* Ehrh.) root sprouts often form dense understories that interfere with tree reproduction throughout much of the eastern hardwood region. The cut-stump treatment, whereby herbicide is applied to the stump within a few hours after a larger beech is felled, has been shown to mitigate the interference problem by eliminating beech stems attached to the parent tree's root system. Forest managers are often reluctant to prescribe this treatment because the short time interval between felling the tree and applying herbicide requires the applicator to work in proximity to an active logging operation, raising concerns about safety and efficiency. This study measured the efficacy of the cut-stump treatment on American beech root and stump sprouts for eight time intervals, ranging from 1 to 120 hours, on a 60-acre study site in central West Virginia. Glyphosate as Razor Pro herbicide was diluted to a 65.6% solution with water (26.9% active ingredient) and applied to the outer 2 in. of beech stumps from trees 11–15 in. dbh. The treatments were applied during a cool humid period in September and evaluated 12 months later. Control of root sprouts ranged from 71 to 86%, with no significant differences among the 1- to 96-hour treatments. Efficacy dropped to 50% and 1% for the 120-hour treatment and control treatment, respectively. Stump sprouts were prevented on all stumps treated within 96 hours of tree severing. The results indicated that herbicide can be applied to beech stumps up to four days after severing without reducing control of root and stump sprouts under the conditions in this study. The longer time interval will improve feasibility, safety, and efficiency of the cut-stump treatment. In practice, the effective time interval may vary depending on season of the year and weather conditions.

Keywords: American beech, herbicides, glyphosate, cut-stump treatment, time interval, root sprouts, stump sprouts

American beech (*Fagus grandifolia* Ehrh.) is an important component of forests throughout much of the eastern hardwood region. Its native range extends from Minnesota to eastern Canada and includes the Central Hardwood, mid-Atlantic, and Gulf Coast regions (Tubbs and Houston 1990). It exhibits two important silvical characteristics that have led to problems for forest managers who seek to regenerate mixed hardwood stands. First, American beech is very shade tolerant and forms dense, persistent understories in the presence of larger overstory parent trees. Studies have shown that dense understories of shade-tolerant species such as American beech can interfere with the establishment and development of desirable shade-intolerant reproduction in Pennsylvania, West Virginia, and New England (Horsley 1991, Horsley and Bjorkbom 1983, Kelty 1988, Miller et al. 2004, Nyland et al. 2006). New seedlings that germinate beneath beech understories do not receive enough sunlight to survive and grow into larger size classes necessary for long-term regeneration success. Once a dense understory cover of beech root sprouts has become established, it tends to persist and interfere with desirable tree reproduction for decades. Second, American beech regenerates primarily by root sprouting in undisturbed stands as well as those subjected to periodic harvesting or other disturbances to the soil and overstory. In West Virginia, more than 90% of advanced beech reproduction originated from root sprouts (Kochenderfer et al. 2004, 2006). Leak (2009) found that American beech understories increased after 70 years of light harvests or no harvests in northern hardwood stands up to 2,700 ft elevation in New Hampshire. He attributed the aggressiveness of understory beech to its high shade tolerance and ability to form root suckers after even minimal disturbance. The number of live beech root sprouts nearly doubled, with virtually no soil disturbance or root injury, after all beech stems $\geq$ 6.0 in. dbh were simply felled and left in place (Kochenderfer et al. 2006). Houston (2001) attributed beech root sprout increases following thinning in New England to root injury caused by the harvesting operation and increased sunlight, but he pointed out that even minor disturbances can stimulate root sprouting. In Maine, the development of dense thickets of beech root sprouts was stimulated in stands affected by beech bark disease and/or harvesting of older beech trees (Houston 1975, Ostrofsky and McCormack 1986). Dense beech root sprout reproduction can occur on fair, good, or excellent growing sites, but it tends to be most abundant on the good sites (Trimble 1973).

Other factors have contributed to the emergence of American beech as a significant interference problem in regenerating hardwood forests. Most hardwood stands in the central Appalachians have been subjected to some type of repeated partial harvesting since the original forests were heavily logged from 1900 to 1920. A recent survey of commercial harvests indicated that diameter-limit cutting had been used on 80% of the stands in West Virginia (Fajvan et al.

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1998). These diameter-limit harvests often remove only merchantable, sawtimber-sized trees, leaving a residual overstory that has the same effect on regeneration and species composition as single-tree selection practices (Miller and Smith 1991). Research studies have demonstrated that single-tree selection practices in the central Appalachians favor the establishment and development of shade-tolerant species such as American beech (Trimble 1973, Lamson and Smith 1991). With a continuous cover of overstory trees, shade-tolerant species flourish at the expense of more shade-intolerant species after partial cutting, thus promoting a long-term decline in species diversity (Miller and Kochenderfer 1998). Because shade-tolerant understories respond positively to repeated partial overstory harvests, such harvest practices can lead to a site conversion dominated by shade-tolerant species (Nyland et al. 2006).

Remedial treatments for reducing or eliminating American beech interference are limited. Mechanical methods, whereby American beech stems are simply severed or mowed, are not effective because new root sprouts develop soon after treatment, often making the problem worse. Other treatments such as prescribed fire or herbicide foliar sprays also have drawbacks. Prescribed fire is a broadcast treatment that may have inconsistent results depending on fire conditions. There is also a risk of damaging desirable trees or other consequences that are inconsistent with management objectives. In mixed-oak forests in Ohio, three to five repeated applications of prescribed fire within a 9-year period led to partial control of shade-tolerant species in the understory (Hutchinson et al. 2012). In New York, two spring prescribed fires applied three years apart in transition oak stands did not control understory beech interference (Nyland et al. 2006, Johnson 2000). In south central New York, a single prescribed fire did not control understory beech root sprouts and may have stimulated more sprouts to emerge (Swan 1970). Broadcast herbicide foliar sprays can be used to treat larger areas during the growing season, but the herbicide active ingredient is not selective, and the spray mist can damage desirable vegetation as well as the intended target species. In addition, the spray mist may not reach foliage ≥ 15 ft tall, thus leaving larger beech stems alive and a possible source of new root sprouts. Target-specific herbicide treatments can also be applied to manage forest vegetation, but it can be very expensive, perhaps prohibitive, to apply them to large numbers of small individual stems (Zedaker 1986). In treating individual stems, cut-surface or stem injection is the most effective way to introduce an herbicide into a plant (Leonard 1963). Cut-stump treatments provide an alternative to treating numerous individual stems in cases where larger stems of root-sprouting species are being cut and control of their root spouts is a silvicultural objective. This manual, target-specific application method is especially suited to steep topography and small ownerships where other vegetation management practices such as mechanical, prescribed fire, or broadcast foliar spray treatments might not be feasible.

Examples of the cut-stump treatment, how it is used to manage forest vegetation, and how to mix recommended herbicides were presented by Kochenderfer et al. (2012a). This treatment is not recommended during heavy sap flow from late winter to early spring in the central Appalachians. Several studies have illustrated that the cut-stump treatment using glyphosate herbicides is an effective method for controlling both beech stump and root sprouts by treating relatively few cut stumps per acre. A 100% solution of glyphosate as Roundup (41.0% active ingredient (a.i.), 4.0 pounds acid equivalent (a.e.)/gallon herbicide), applied to the stumps of various Piedmont hardwood species immediately after severing, controlled 69–98% of stump sprouts (Zedaker et al. 1987). A 100% solution of glyphosate as Glypro (53.8% active ingredient (a.i.), 5.4 pounds acid equivalent (a.e.)/gallon herbicide), applied to the outer 2 in. of beech stumps that averaged 11 in. in diameter within one hour after severing, controlled > 90% of beech root sprouts ≥ 1.0-ft tall up to 5.9-in. dbh (Kochenderfer et al. 2006). The herbicide was translocated from the surfaces of treated beech stumps via parent root systems to the most active growing parts of attached beech stems as described by Anderson (1996). Root sprout control was strongly correlated with stump size, with effective root sprout control increasing with the diameter of the cut stump.

A subsequent cut-stump study established in a northern hardwood stand in central West Virginia demonstrated that a 50% solution of Glypro, applied to the outer 2 in. of beech stumps, was just as effective as a 100% solution and that herbicide could be applied up to four hours after beech stems had been severed without reducing efficacy on root sprouts (Kochenderfer and Kochenderfer 2009). Average efficacy for all treatments was 85% control of beech root sprouts ≥ 1.0-ft tall up to 5.9 in. dbh. The study was established in a stand where several large overstory beech had been removed in past partial harvests, presumably leaving numerous sprouts from their root systems. The beech trees severed to study the cut-stump treatment were probably large root sprouts from the parent trees that had been removed decades earlier. The study demonstrated that the cut-stump treatment would be effective in controlling beech root sprouts whose origins traced back to several generations of parent trees or back to intraspecific root grafts common in American beech (Graham and Boremann 1966). Kochenderfer and Kochenderfer (2009) also found that labor and volume of herbicide solution used was slightly greater for the 100% solution of Glypro herbicide compared to the 50% solution of the same product. The authors observed that the 100% solution of Glypro was more viscous, which made it more difficult for the herbicide to spread and cover the cut-stump surfaces. Lower herbicide concentrations further reduced treatment costs and the potential for negative impacts on nontarget species.

The label for glyphosate as Razor Pro herbicide recommends applying a 50–100% solution to the entire cambium of the stump surface immediately after severing. It cautions that delays in application may reduce performance, and that best results are obtained when applications are made during active growth and full leaf expansion. Other references recommend applying herbicide to stumps within four hours after severing, the sooner the better, to control stump sprouting of many species (USDA Forest Service 1994).

Extending the time interval between severing the tree and applying herbicide to the stump would allow forest managers to improve the feasibility, safety, and efficiency of the cut-stump treatment. Feasibility is improved because the cut-stump treatment and the logging operation can be carried out as distinct projects by separate contractors who have the appropriate licenses and equipment for each job. In the past, requiring stumps to be sprayed within a short time interval posed a significant barrier to applying the cut-stump treatment; loggers were reluctant to become herbicide applicators and herbicide applicators were reluctant to work around active logging operations for reasons related to both safety and efficiency. A longer time interval would improve safety because herbicide applicators would not be exposed to the dangers from falling trees and logging equipment if spraying stumps can be delayed until logging is completed in designated areas of an active harvest operation. This is

Figure 1. The ability to delay application of herbicide to cut stumps for as long as 4 days enabled applicators to use this treatment on mechanized harvesting operations in central West Virginia.

especially true on highly mechanized operations where feller-bunchers and wheeled skidders are being used (Figure 1). Efficiency is improved after felling and skidding are complete because applicators can access the site with equipment and herbicides, move from stump to stump without delay, have enough treatable stumps to keep busy, and treat stumps that were covered by logging slash. In addition, applicators can better focus on properly treating every cut stump, thus resulting in fewer missed stumps and more thorough application of the herbicide on each stump. Although not used in this study, a dye can be added to the herbicide solution to further improve efficiency and avoid missing stumps.

The objective of this study was to determine if extending the time interval between severing the tree and applying herbicide to the cut stump beyond four hours would reduce the efficacy of the cut-stump treatment on American beech root and stump sprouts.

Methods

Study Area

The 60-acre study site is located in the Allegheny Mountain region at an elevation of 3,100 ft, near the community of Pierce in central West Virginia, on land owned and managed by Western Pocahontas Properties. The species composition was typical of many northern hardwood stands in the eastern hardwood region where periodic harvesting has occurred, with most of the overstory basal area occupied by American beech and red maple (*Acer rubrum* L.), with smaller amounts of sugar maple (*A. saccharum* Marsh.) and black cherry (*Prunus serotina* Ehrh.) (Table 1). Yellow birch (*Betula alleghaniensis* Britton) occupied less than 2% of the basal area, although it may have been more abundant before commercial harvests and other disturbances led to the species mix present when this study was installed. The American beech component of this stand consisted of larger and older residual trees left after earlier harvests along with a rather dense poletimber, sapling, and root sprout component in the understory that was well distributed throughout the study site. Over 50% of the stand basal area was occupied by American beech, with over 6,000 beech stems/ac $<$ 1.0 in. dbh that are not included in the basal area estimate in Table 1. Smaller amounts of striped maple (*A. pensylvanicum* L.) and serviceberry (*Amelanchier arborea* (Michx. f.) Fernald) were also present in the understory.

Several factors led to the abundance and dominance of American beech in both the overstory and understory (Table 1). The general vicinity of the study site was heavily logged around 1900 (Fansler 1962), followed by several partial harvests since the 1950s, with the most recent partial harvest occurring in 1995. In each instance, harvesting focused on removing commercially valuable species such as black cherry, sugar maple, and yellow birch. Some red maple and American beech were removed as well, but only if individual trees contained relatively high-quality logs. Otherwise the residual stand after each harvest contained a higher proportion of overstory American beech than before. Moreover, each harvesting operation disturbed the soil, damaged beech root systems, and increased sunlight. Periodic wildfires may also have disturbed the study site from time to time. All of these factors stimulated the development of more beech root sprouts to join those already present. As the beech root sprouts increased their dominance of the understory over decades, they formed a layer of low shade and interference, further preventing new black cherry, yellow birch, and maple seedlings from developing into competitive advanced reproduction. It is conceivable that the increase in understory beech interference had been ongoing for over 100 years when this study was installed.

Experimental Design and Treatments

The experiment was based on a completely randomized design. The treatments consisted of eight different time intervals shown in Table 2, varying from 1 to 120 hours, between the time of felling a sawtimber-size American beech and applying herbicide to its stump. A control treatment was also included, whereby the tree was felled but no herbicide was sprayed on its stump. The American beech trees selected for this study ranged in size from 11.0 to 15.0 in. dbh. A concerted effort was made to select similar sized trees because previous research had demonstrated that efficacy of the cut-stump treatment on root sprouts was related to stump size (Kochenderfer et al. 2006). In addition, each selected tree had numerous small beech stems growing beneath it, most of which were presumed to be root sprouts from the tree's root system. To isolate the effect of the herbicide treatment on control of root sprouts and stump sprouts around individual trees, the selected trees were a minimum of 100 ft apart. Although no spatial analysis was conducted, the locations of the trees were mapped using global positioning systems (GPS) coordinates to facilitate relocating the trees for applying treatments and collecting data. Forty American beech trees meeting these criteria were selected on the 60-acre study site. Each of the eight time interval treatments was randomly assigned to five trees, and then one tree in each of the time interval treatments was randomly assigned to serve as a control with no herbicide applied to its cut stump. A few days before the selected beech trees were felled, all dead beech stems $>$ 1.0 ft tall were removed within a 26.3-ft radius around the trees, thus forming a 0.05-ac circular plot in which all stems were alive.

The selected American beech trees were felled manually with a chainsaw and left in place to minimize disturbance to the plots in September 2008. Their cut stumps were then sprayed once with herbicide solution at the various time intervals presented in Table 2. The herbicide used in this study was glyphosate as Razor Pro (41.0% a.i., 4.0 pounds a.e./gallon) in a water carrier. Razor Pro was used because it includes a labeled 14% surfactant concentration, which is

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

Species	Dbh size classes					Basal area
	< 1.0 in.	1.0–5.9 in.	6.0–11.0 in.	> 11.0 in.	Total	
	. . . . .no. stems/ac.					. . ft^2/ac. .
American beech	6,365	184	41	26	6,616	48.7
Red maple	–	4	8	16	28	22.6
Sugar maple	–	10	13	5	28	10.6
Black cherry	–	10	1	7	18	9.8
Yellow birch	–	4	3	1	8	1.8
Striped maple	–	72	0	0	72	1.1
Serviceberry	–	1	1	0	2	0.2
All species	6,365	285	67	55	6,772	94.8

Table 2. Tree severing (Sept. 10, 2008) and herbicide application schedules used in the study.

Treatment	Time tree severed	Time herbicide applied	Plot numbers
1-hour	8 am	9 am (same day)	17, 36, 9, 30, 5*
8-hour	9 am	5 pm (same day)	1, 24, 18, 27, 11*
16-hour	3 pm	7 am (next day)	10, 21, 28, 35, 6*
24-hour	10 am	10 am (next day)	37, 29, 33, 14, 7*
48-hour	11 am	11 am (2 days)	39, 2, 31, 8, 3*
72-hour	1 pm	1 PM (3 days)	23, 16, 13, 20, 26*
96-hour	2 pm	2 pm (4 days)	4, 15, 19, 12, 32*
120-hour	3 pm	3 pm (5 days)	22, 25, 40, 38, 34*

* Randomly selected control plots; the tree was severed, but no herbicide was applied to its cut stump.

recommended to aid in penetration of cut-stump treatments by Miller (2003). The herbicide solution was diluted to 65.6% Razor Pro in water, thus the solution applied to the stumps in this study was actually 26.9% active ingredient glyphosate. This concentration was equivalent to the 50% solution of Glypro (53.8% a.i., 5.4 pounds a.e./gallon) used in an earlier cut-stump study where the herbicide was applied in June four hours after the trees were cut (Kochenderfer and Kochenderfer 2009). Applying an equivalent herbicide solution in this study provided a means to isolate the effect of extending the time interval on the control of beech root sprouts and stump sprouts. A plastic spray bottle calibrated to apply 0.9 ml per squirt was used to dispense 3.5 ml (0.12 fluid ounces) of solution per inch of stump diameter to the cut stumps. Previous experience indicated that this amount of solution was sufficient to wet the outer 2-in. band around the perimeter of each stump. Sawdust was removed from the stumps before treatment. The diameter of each stump was measured to determine the proper dosage of herbicide solution (number of squirts per stump). For consistency, the same person applied the herbicide on each plot.

Within a week after the treatments were applied, fixed-area circular plots were used to inventory live trees around the cut stumps. A 0.5-in. hole was drilled in the center of each stump and a 4.0-ft section of 0.5-inch rebar was inserted into the hole to serve as plot center and facilitate accurate plot measurements. Live trees of all species ≥ 1.0-in. dbh within the 0.05-ac plots (26.3-ft radius) centered at each stump were tagged and numbered, with species and dbh recorded for each tagged tree. Similarly, all beech stems ≥ 1.0-ft tall and < 1.0-in. dbh were tagged within a smaller 0.01-ac circular plot (11.8-ft radius) centered at each stump. Stem counts within the 0.01-ac plots were recorded for the tagged beech stems in three size classes: 1.0-ft to 6.0-ft tall, ≥ 6.0-ft tall to 0.9-in. dbh, and ≥ 1.0-in. dbh.

Efficacy Evaluations

The efficacy of the herbicide treatments on stump sprouting and on beech stems within the plots was evaluated in September 2009, about 12 months after treatment. For stump sprouting, stumps with no live sprouts were considered controlled. For beech stems within the plots, a numerical rating system was used to evaluate the percent of crown control on each individual stem. All beech stems ≥ 1-in. dbh on the 0.05-ac plots and all beech stems ≥ 1.0-ft tall and < 1.0-in. dbh on the 0.01-ac plots received a rating. Each stem received a rating of 1 to 7, which represented 0, 7, 25, 50, 75, 93, and 100% crown control, respectively (Memmer and Maass 1979, Gnegy 1991, Kochenderfer et al. 2001). For example, a beech stem whose crown was less than 7% controlled received a rating of 1, and a stem whose crown was between 75 and 93% controlled received a rating of 5. Two observers independently rated the crown control on all trees within each plot. The mean ratings for each plot showed no discernible bias between observers, so the ratings were not adjusted. Trees with a mean efficacy rating of 5.0 or higher (75% crown necrosis) were considered controlled. Experience with this approach to efficacy evaluations since 2001 has confirmed that the rating system is reliable, and beech stems with ≥ 75% crown necrosis after one year do not survive (Kochenderfer et al. 2001).

Statistical Analyses

The numerical rating system of crown control on individual beech stems within the 11.8-ft radius plots was used to determine the efficacy of the herbicide treatments on beech root sprouts by size class (percent controlled) in each plot (Figure 2). There were four observations (plots) for each size class in each of the time interval treatments and eight observations (plots) in each size class in the control treatment. Because the response variables represented a percentage, a generalized linear mixed model via Proc GLIMMIX with a beta distribution and a logit link function was employed to compare the mean efficacy of the treatments (SAS 2011). Size class category and treatment were the fixed model effects and size class category within plot was a random effect. The Kenward–Rogers denominator degrees of freedom were used. Least Squares Means for treatment, size class category, and the interaction were evaluated using the Tukey–Kramer adjustment. The type I error rate was set at

Figure 2. Typical efficacy of the cut-stump treatment on American beech root and stump sprouts. Note the treated stump, the 15-in. dbh tree on the ground and the tagged root sprout in the foreground.

alpha = 0.05. Similarly, the 40 beech stumps were evaluated to determine the efficacy of the herbicide treatments on stump sprouts. There were four observations (stumps) in each of the time interval treatments and eight observations (stumps) in the control treatment.

Results

Efficacy on root sprouts within the 0.01-acre plots (11.8-ft radius) surrounding the stumps was similar for the 1- to 96-hour time intervals, followed by a significant reduction in efficacy for the 120-hour time interval, and virtually no efficacy for the control treatment (Table 3). Within the eight time interval and control treatments, efficacy on beech root sprouts was not significantly different by size class for the small (≥ 1-ft to 6-ft tall), medium (≥ 6-ft tall to 0.9-in. dbh), and large (≥ 1.0-in. dbh) stems. Considering all size classes combined, mean efficacy on root sprouts varied from 71 to 86% for stumps sprayed with herbicide within 4 days after severing. For the 120-hour interval and control treatments, mean efficacy on root sprouts dropped to 50% and 1%, respectively.

The cut-stump treatment was also effective at preventing stump sprouts. All four stumps in each of the 1- to 96-hour time interval treatments had no stump sprouts, and three of the four stumps in the 120- hour treatment had no stump sprouts one year after treatment. In each case, it was evident that the herbicide treatment prevented emergence of stump sprouts, i.e., stump sprouts did not emerge and die back later. All eight stumps in the control treatment and one stump in the 120-hour treatment had live sprouts after one year.

Although this study was conducted on a single 60-acre study site, and the cut-stump treatment was applied during favorable humidity conditions in September, the results demonstrated that the effective time interval between severing beech trees and applying herbicide to their cut stumps was much longer than previously observed.

Discussion

The primary objective of this study was to determine if the time interval between tree severing and application of herbicide to the cut stump could be extended beyond four hours without reducing efficacy on beech root or stump sprouts. A previous study conducted in June showed that the time interval could be extended from 1 hour up to 4 hours without reducing efficacy when applying a solution of 26.9% active ingredient glyphosate (Kochenderfer and Kochenderfer 2009). Using an equivalent herbicide concentration, this study conducted in September indicated that the time interval could be extended up to 96 hours (4 days) without reducing efficacy. Consistent with the previous study, the results also indicated that the cut-stump treatment was equally effective for all size classes of beech root sprouts (Table 3). Also similar to the previous study, sprouts did not develop on any stumps sprayed with herbicide within four days of severing.

Although the cut-stump treatment controlled a relatively high percentage of beech root sprouts in the 1- to 96-hour time intervals, many stems in each plot were not affected. It is presumed that the unaffected stems were not attached to the root system of the treated cut stump and did not receive any herbicide. Instead, they were likely seedling-origin stems or root sprouts arising from other beech trees located on or nearby the plots. In practice, the cut-stump treatment would be applied to several beech trees per acre, many with overlapping root systems, thus resulting in greater efficacy on root sprouts than observed in this study. For example, the cut-stump treatment applied to all beech trees ≥ 6.0-in. dbh within a northern hardwood stand in West Virginia controlled greater than 95% beech root sprouts and all beech stump sprouts (Kochenderfer et al. 2006).

While larger beech trees may appear to be individual stems, they are often connected to roots of parent trees and perhaps by root grafts to other beech trees, thus forming large connected root systems (Kochenderfer et al. 2006). The authors of that study concluded that glyphosate applied to a cut stump is probably translocated through the xylem along gradients to active growth regions of attached root sprouts and other beech stems attached through root grafts. Once the parent stem is severed, the herbicide tends to migrate to the most active regions of plant growth as described by Anderson (1996). True et al. (1955) used solution reservoirs attached to the tops of freshly cut northern red oak (*Quercus rubra* L.) stumps to study absorption of solutions through stump surfaces. They found that solution uptake was stimulated and the period of most rapid absorption was prolonged to 4 days or longer when live companion sprouts were attached to the stump or when other trees were attached to the stump's root system by root grafts. After an extensive literature survey on natural root grafts, Graham and Bormann (1966) concluded that root grafts were common in many forest species, including self-grafts and intraspecific grafts (within same species) for American beech. In this study, the mortality of untreated beech stems near beech stumps treated with glyphosate, an herbicide that does not exhibit soil activity, tends to confirm the movement of glyphosate through an intraspecific connection of root systems. However, interspecific root grafts (between different species) are rare (Graham and Bormann 1966). The cut-stump treatment examined in this study was applied exclusively to beech stumps and did not damage other species found on the 26.3-ft radius treatment plots.

Reductions in efficacy of cut-stump treatments following delays in application have been attributed to reduced herbicide absorption caused by drying of stump surfaces. Meteorological data collected from a weather station near the study site showed that cool, wet conditions were prevalent during the 6-day period when these cut-stump treatments were applied (Table 4). Average, minimum, and

Table 3. Mean number of beech stems per acre and mean percent of beech stems controlled* by size class and treatment time interval between tree severing and application of herbicide to the stump.

Time interval	All size classes**								
	1-ft to 6-ft tall		≥ 6-ft tall to 1-in. dbh		≥ 1-in. dbh		All size classes**		
	Initial	Controlled	Initial	Controlled	Initial	Controlled	Initial	Controlled	
	no./ac	%	no./ac	%	no./ac	%	no./ac	%	SE
1-hr	4,625	74	1,750	89	350	86	6,725	78[a]	6.2
8-hr	5,750	67	1,125	89	475	79	7,350	71[a]	5.0
16-hr	4,550	88	2,050	83	475	79	7,075	86[a]	4.0
24-hr	3,925	83	1,350	67	375	73	5,650	79[a]	5.1
48-hr	3,225	80	1,200	79	350	86	4,775	80[a]	3.6
72-hr	3,700	82	1,250	78	425	82	5,375	81[a]	5.2
96-hr	3,500	76	1,325	81	425	65	5,250	76[ab]	8.1
120-hr	3,500	50	1,900	47	825	58	6,225	50[b]	16.3
Control	4,763	2	2,400	0	450	0	7,613	1[c]	0.5

* Beech root sprouts with ≥ 75 percent crown necrosis 1 year after treatment were deemed to be controlled.
** Time intervals followed by the same letter are not significantly different at the 0.05 level (using Tukey–Kramer grouping for treatment least squares means).

Table 4. Weather conditions at the Pierce study site during the herbicide treatments.

Date	Average daily temperature	Minimum daily temperature	Maximum daily temperature	Average daily relative humidity	Precipitation*
	. . . .	.deg F		(percent)	(in.)
9/10/2008	53.2	49.1	60.1	88.8	0
9/11/2008	59.9	53.6	66.4	88.2	0
9/12/2008	61.9	59.0	64.0	100.0	0.62
9/13/2008	66.2	61.9	70.2	93.2	0.01
9/14/2008	69.8	61.2	79.0	74.5	0.14
9/15/2008	56.1	51.8	59.9	92.0	0.10

* All table entries except precipitation were based on hourly mean values.

maximum temperature averaged 61.2° F, 56.1° F, and 66.6° F, respectively. Relative humidity averaged 89.5%. Rain showers occurred during four of the six days. A total of 0.87 in. of precipitation fell over the 6-day period. These cool temperatures, high humidity, and precipitation may have acted to slow the drying of the surfaces of the cut stumps, making them able to effectively absorb the herbicide for a longer period of time compared to relatively dry conditions. Along with the weather conditions, the treated stumps were partially shaded by the surrounding trees. Evaporation is typically less in small forest gaps, like the ones created in this study, compared to open conditions (Patric and Goswami 1968). In practice, the effective time interval for applying herbicide to cut beech stumps may be reduced under conditions that differ from those observed this study.

Management Implications

The cut-stump treatment is a target-specific herbicide application method that can be used to provide long-lasting control of beech root and stump sprouts in forest stands. It can be done in conjunction with commercial operations where merchantable beech and other species are harvested, or it can be applied as a noncommercial treatment where beech trees are simply felled and left on the site. It can be applied on large or small areas, depending on management objectives and on the severity of the beech interference problem. The simplicity and minimal equipment requirements enable small forest landowners to apply it themselves on their own properties. The ability to wait up to four days before treating severed stumps can increase the feasibility, safety, and efficiency of the treatment.

This study was conducted on a single study site under relatively favorable humidity conditions in late summer. Several factors can affect the degree of success possible when using the cut-stump treatment to control beech interference. First, the efficacy of cut-stump treatments may be reduced in hot, dry weather conditions, so it is advisable to apply the herbicide as soon as possible after trees are severed, once concerns about safe and efficient access to the severed stumps are addressed. Second, this treatment should not be used during heavy sap flow that usually occurs from February to leafout in the central Appalachians. During that period of the year, sap can exude from cut surfaces and prevent the herbicide from entering the root system. Third, careful planning of logging operations will facilitate safe and efficient application of the cut-stump treatment on active operations. It is advisable to begin at an outside boundary of the harvest unit and to complete logging activities within a relatively small area, say four or five acres, before moving to a new area so that herbicide applicators can safely locate and treat all of the beech stumps in one visit. Although not used in this study, a glyphosate dye can be used to enhance coloration of the herbicide solution, which helps workers properly spray and keep track of treated stumps. Finally, the cut-stump treatment is most effective where there are enough freshly cut beech stumps in proximity to an undesirable beech understory to disperse the herbicide to a relatively wide area via their root systems. Kochenderfer and Kochenderfer (2009) provided some insight on the number of treatable beech stumps that are required in order for this treatment to be effective. If large stumps are not available, treating numerous small stumps can also control beech interference. For example, the cut-stump treatment was effective on two commercial mechanized fiberwood harvesting operations near the study site totaling 55 acres. Stand structure was similar to that shown in Table 1. All beech stumps ≥ 2.0 in. in diameter were treated in July and August with 50% solution of Razor Pro herbicide in a water carrier with Hi-Light dye added

(Figure 1). Sawdust and dirt were removed from stumps prior to treatment. The average application rate was 3.0 gallons of herbicide solution per acre. Treatment of numerous small stumps was considered prudent because of the scarcity and lack of a uniform distribution of larger stumps on much of the area. The cost of treating numerous small stumps was comparable to treating fewer large stumps because applicator labor and volume of herbicide per acre is about the same in both situations.

If treatable beech stumps are sparse within an area, stem injection treatments are an alternative target-specific method for controlling beech interference (Kochenderfer et al. 2012b). Although stem injection is not as effective on untreated stems as the cut-stump treatment, it will control both injected trees and a large proportion of beech root sprouts associated with them.

When glyphosate herbicide is applied solely to beech stumps, the cut-stump treatment will control only beech stump and root sprouts connected by various means to the root systems of treated stumps. Other woody species on the site will not be affected. Similarly, the cut-stump treatment does not control other common interfering plants like grass and ferns. However, other woody species that pose an interference problem such as striped maple, blackgum (*Nyssa sylvatica* Marshall), sassafras (*Sassafras albidum* (Nutt.) Nees), and tree-of-heaven (*Ailanthus altissima* (Mill.) Swingle) can be severed during harvesting operations and their stumps treated in conjunction with the primary target species. While this study focused on controlling American beech, additional research is needed on the efficacy of the cut-stump treatment on other woody species known to produce interfering stump and root sprouts.

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