Preharvest Manual Herbicide Treatments for Controlling American Beech in Central West Virginia

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ABSTRACT: *Application costs and efficacy were determined for manual preharvest herbicide treatments applied to control American beech (*Fagus grandifolia *Ehrh.) that was interfering with the establishment and development of black cherry (*Prunus serotina *Ehrh.) in central West Virginia. The treatments consisted of four levels of basal area reduction using combinations of two application methods: hack-and-squirt injection with Accord (41.5%) and basal spraying with Garlon 4 (61.6% butoxyethyl ester). The treatments were applied in late Aug. 2000 and evaluated 12 months after treatment. A numerical rating system ranging from 1 to 7 (0–100% crown affected), based on a visual estimation of top kill, was used to evaluate the efficacy of each treatment. Trees receiving a rating of 5 (75% crown control) or greater were considered controlled. After 12 months, almost complete control (99%) was achieved with both application methods. Injection of ≥6.0-in. dbh beech stems also controlled 52% and 21.6% of small untreated beech understory stems in the 2-ft tall to 0.9-in. dbh and 1.0- to 5.9-in. dbh classes, respectively. Average application costs (chemical and labor) ranged from $39.28/ac for injection of 159 stems/ac ≥6 in. dbh to $80.32/ac for basal spraying 396 stems/ac in the 1.0- to 5.9-in. dbh class and $230.09/ac for basal spraying 3,743 stems/ac in the 2-ft tall to 0.9-in. dbh class. Basal spraying the numerous small 2-ft tall to 0.9-in. dbh stems dramatically increased treatment costs. Black cherry occupied 30% of total stand basal area and accounted for 91% of total stand value ($6,288.10/ac). Application costs expressed as a percentage of total stand value ranged from <1% for the injection-only treatment up to 6.5% for combination basal spray and injection treatments. The individual stem herbicide application methods described here are applicable to the steep topography and small nonindustrial ownerships found in Appalachia. North. J. Appl. For. 21(1):40–49.*

Key Words: Herbicides, American beech, manual application methods, Appalachian hardwoods, silviculture, economics.

The heavy cutting at the turn of the century in the central Appalachians often resulted in the establishment and subsequent development of a diverse mix of commercial hardwoods, which included some of our most valuable shade-intolerant species. Since these early harvests, most stands have been subjected to some type of repeated partial cutting. A recent survey by Fajvan et al. (1998) indicated that diameter-limit harvesting had been used on 80% of the stands surveyed. Many stands have been subjected to more than one such cut, although repeated diameter-limit cutting has not been a recommended practice (Hutnik 1958, Trimble 1971). The diameter-limit cuts that were used often only removed sawtimber sized trees that have 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 (*Fagus grandifolia* Ehrh.), red maple (*Acer rubrum* L.), and on the best sites, sugar maple (*Acer saccharum* Marsh.) (Trimble 1965 and 1973, Lamson and Smith 1991). Other investigators, e.g., Sander and Clark

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(1971), have concluded that the development of tolerant reproduction continues to expand at the expense of more shade-intolerant species after partial cutting, which eventually leads to a decline in species diversity (Miller and Kochenderfer 1998). Dense understories of undesirable shade-tolerant species such as beech and striped maple (*Acer pensylvanicum* L.) can interfere with the establishment and development of desirable shade-intolerant species including black cherry (*Prunus serotina* Ehrh.), white ash (*Fraxinus americana* L.), northern red oak (*Quercus rubra* L.), and yellow-poplar (*Liriodendron tulipifera* L.) (Horsley and Bjorkbom 1983, Horsley 1991).

In the past few years, there have been dramatic increases in stumpage prices for several Appalachian hardwood species, especially black cherry, stimulating interest in managing this species more intensively. It has been observed elsewhere (Zedaker 1988) that as more intensive management evolves in response to resource value increases, vegetation management involving the use of herbicides and other cultural methods will be used to focus site resources on the most desirable species. It is fortunate that two of the most valuable timber species in the central Appalachians, i.e., black cherry and northern red oak, are also the most valuable species for wildlife in the region (Miller and Kochenderfer 1998).

Research has shown that controlling interfering plants several years before a planned harvest can increase the proportion of desired species that regenerate successfully after harvest (Marquis et al. 1975). To further our understanding of preharvest control options, a study was established in West Virginia during the summer of 2000 to evaluate herbicide treatments that could be used to control low-value species, primarily American beech that was interfering with the establishment and maintenance of a relatively high proportion (e.g., >50%) of black cherry, on commercial growing sites in the Appalachians. This article presents information on production rates, application costs, and efficacy of basal spray and injection herbicide treatments used for controlling American beech. Results of this study provide treatment options applicable to the steep topography and small ownerships common to Appalachia.

Methods

Study Area

The study site is located in the southern extension of the Allegheny hardwood forest on a 1,200-acre tract of private land in central West Virginia. It was first cut around 1900 (Fansler 1962), when the stand contained a red spruce (*Picea rubens* Sarg.)-hemlock (*Tsuga canadensis* L. Carr.) component. Residual logs, knots, and root mounds indicate that there was a conifer component in the original stand, although no conifers are present today. The conifers were most likely eliminated by fire that followed logging in much of the surrounding area. Partial cuts, which removed mostly smaller stems for mine props and pulpwood, were made in the 1960s. There is a dense beech understory present throughout the stand. Advance regeneration evaluation guidelines developed for Allegheny hardwoods (Marquis et al. 1975) consider 6-ft radius plots containing eight stems of beech or striped maple to be heavily stocked with undesirable competition that will interfere with desirable regeneration. A survey of reproduction on the treatment plots indicated that 90% of the 6-ft radius plots had eight or more beech stems less than 1.0 in. dbh on them.

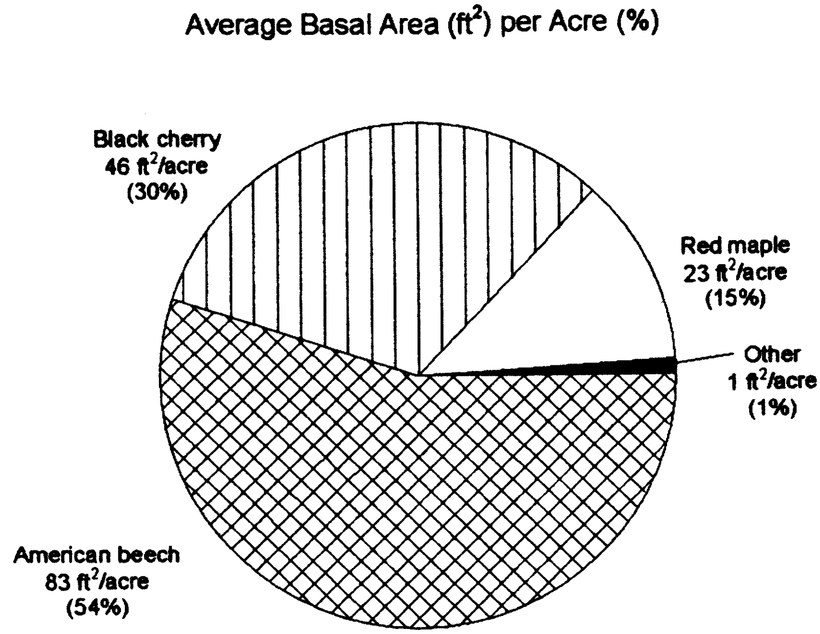
Stand size class distribution of basal area and number of stems is shown in Table 1. Most of the stems (86%) are <1.0 in. dbh, but 84% of stand basal area is in trees >6.0 in. dbh. The current stand has an average basal area of 153.4 ft^2/ac in stems 1.0 in. dbh and larger. Basal area distribution by species is shown in Figure 1. Black cherry and red maple accounted for 45% of total stand basal area. Trees merchantable for sawtimber or veneer represented 38% of the total stand basal area. These were dominant and co-dominant black cherry and red maple trees ≥11.0 in. dbh. The remainder of the stand basal area (55%) consisted mainly of American beech, which is only merchantable for fiberwood at this location. Fiberwood weights for trees ≥6.0 in. dbh were based on a 4-in. top diameter for merchantable bole length using equations by Brenneman et al. (1978). A breakdown of stand values using local transaction evidence is also shown in Figure 1. The value chart illustrates the importance of species composition in determining stand values in Appalachian hardwoods. Black cherry, which represented 30% of stand basal area, accounted for 91% of stand value, while beech represented 54% of stand basal area and only accounted for 3% of stand value. This wide disparity in species values among Appalachian hardwoods makes species composition a key consideration in management decisions (Kochenderfer et al. 2001).

Design and Treatments

Four treatments were distributed among 16 0.3-acre plots using a complete randomized design. All treatment plots

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

<1.0 in.	1.0–5.9 in.	No. stems 6.0–11.0 in.	>11.0 in.	Total
		(no./ac)		
3,660	392	145	65	4,262
<1.0 in.	1.0–5.9 in.	Basal area 6.0–11.0 in.	>11.0 in.	Total
		(ft^2/ac)		
	24.03	52.77	76.62	153.42



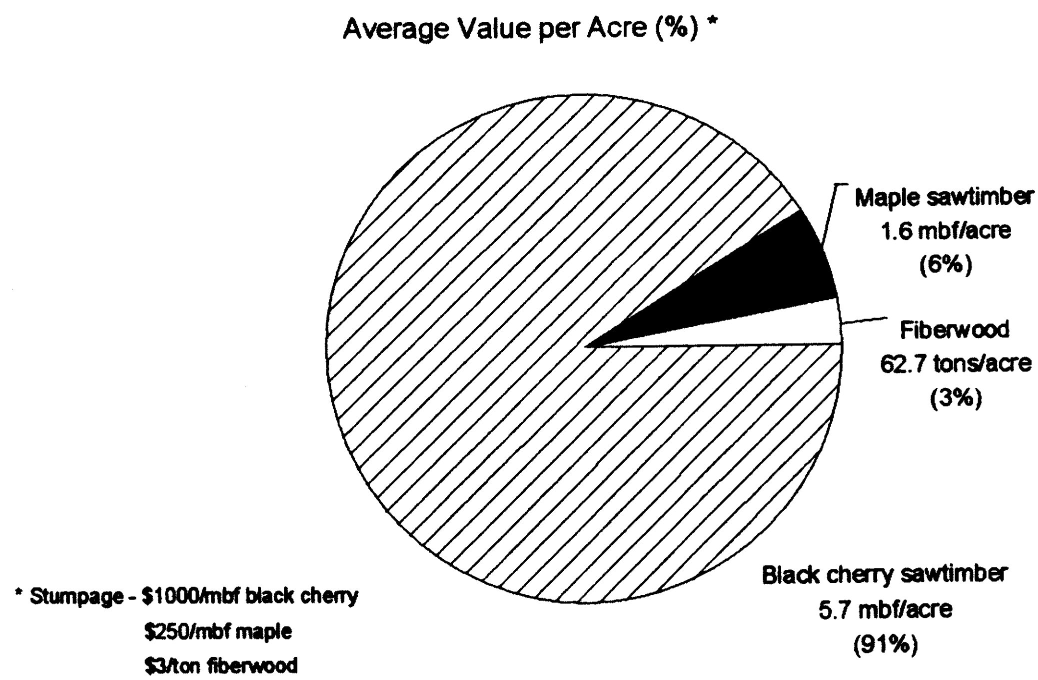


Figure 1. Average stand basal area (top) and value (bottom) for the study site. Based on the following market prices: $1,000/mbf for black cherry, $250/mbf for maple, and $3.00/ton for fiberwood.

were located where black cherry seedlings were well distributed and the density of stems <6.0 in. tall exceeded 1,000/ac. Combinations of injection and basal bark spray applications were used in the treatments. The light treatment consisted of two separate basal spray applications, the medium treatment one injection application, and the heavy treatment two basal spray and one injection application. Two separate applications were used to apply basal spray to the 2-ft tall to 0.9-in. dbh and 1.0- to 5.9-in. dbh stems to collect data for the two size classes. The four treatments included: (1) control, no treatment; (2) light treatment, basal spray of 2-ft tall to 5.9-in. dbh stems; (3) medium treatment, injection of ≥6.0-in. dbh trees; and (4) heavy treatment, basal spray of 2-ft tall to 5.9-in. dbh stems and injection of

≥6.0-in. dbh trees. These treatments were designed to reflect four levels of increasing shade removal ranging from the control to the heavy treatment.

Treatment plots were 114.3 ft × 114.3 ft (0.3 ac) square with 0.05-ac (46.7 ft × 46.7 ft) measurement plots centered within each treatment plot providing a 33.8-ft buffer around the measurement plots. Within each 0.05-ac plot, all stems ≥2 ft tall were tagged. Dbh and species was recorded for each stem ≥1.0 in. dbh, and stem count by species was recorded for stems ≥2 ft tall to 0.9 in. dbh. Nine permanent milacre plots were established on each 0.05-ac measurement plot to monitor reproduction and changes in ground cover. Initial measurements were made on these plots prior to treatment. Beech regeneration was classified as being of root sprout origin on the basis of appearance, the most common characteristic being the occurrence of multiple stems originating at the same location.

A 50% solution of glyphosate (*N*-(phosphonomethyl) glycine as Accord 41.5%) in a water carrier was used in the hack-and-squirt injection application. One incision per inch of dbh was made using a hatchet with a ground-down bit 1.75-in. wide. A meterjet herbicide gun was used to dispense 0.051 fl oz (1.5 ml) of solution into each incision. A 10% solution of triclopyr as Garlon 4 (61.6% 3,5,6-trichloro-2-pyridinyloxyacetic acid, butoxyethyl ester) in a Hy-grade I oil carrier was used for the basal spray applications. A backpack sprayer equipped with an adjustable cone nozzle was used to dispense the herbicide solution. The lower 15 in. of each stem was wetted to the point of runoff. All stems ≥1.0 in. were marked 15 in. above the groundline with a paint marker prior to spraying to ensure consistency among applications. All plots were treated in late Aug. 2000; one applicator was used per plot to apply each herbicide application. A total of four applicators were used in the study to add variability. Application times and the actual volumes of herbicide solutions used for each herbicide application were recorded for each treatment plot. These data were used to compute production rates and application costs.

Efficacy Evaluations

The study was evaluated in late Aug. 2001, 12 months after treatment. A numerical rating system based on a visual estimation of crown control ranging from 1 to 7 (0–100% crown affected) using visual symptoms was used to evaluate the efficacy of each treatment (Memmer and Maass 1979, Kochenderfer et al. 2001). Two observers rated all trees on each plot. The mean ratings for each plot showed no distinct bias among observers, thus no adjustments were made to any of the ratings. A mean treatment efficacy rating was determined for four plots in each treatment. Trees with an efficacy rating of 5.0 or higher (75% crown necrotic) were considered controlled. For statistical analysis, the efficacy ratings were converted into percentages using arc sine transformation (Little and Hills 1978). The mean efficacy ratings were first converted into degrees and then into corrected percentages using arc sine percentage transformation tables (Gomez and Gomez 1984).

All the injected trees in the study were used to determine the efficacy of the injection applications. The effect of the injection applications on untreated stems 2 ft tall to 5.9 in. dbh was also evaluated on the plots receiving the medium treatment. The stems that were sprayed in the light treatment were used to determine the efficacy of the basal spray applications. Similarly, the effect of the basal spray applications on untreated stems ≥6.0 in. dbh was also evaluated on these plots. Treatment effects were analyzed using a one-way analysis of variance (ANOVA) with a complete random factorial design with four observations per treatment. Cost analysis was based on all the species treated in the plots. Measurement of the treatment plots allowed for time and cost comparisons of application methods and treatments.

Results and Discussion

Basal Area Reductions

The reductions in stand basal area associated with each treatment are shown in Figure 2. Basal area reductions for the heavy, medium, and light treatments averaged 98.9 ft^2/ac, 68.1 ft^2/ac, and 23.8 ft^2/ac, respectively. Treatments were restricted to low-value trees unsuitable for sawtimber that would normally be used for fiberwood. American beech was the primary species treated. It accounted for 90% of all the basal area and 99% of the stems less than 1.0 in. dbh treated in the study. Red maple was the next most common species treated, accounting for 9% of the basal area treated. No black cherry trees were treated regardless of size or condition. Residual black cherry basal area averaged 48.7 ft^2/ac on the treated plots.

Production Rates

Average production rates for the injection and basal spray application methods are shown in Table 2. Basal spray applications are normally only recommended for trees up to 6 in. dbh while tree injection is applicable for trees larger than 1.0 in. dbh (USDA Forest Service 1994). Basal spraying stems 2 ft tall to 0.9 in. dbh required much more time than basal spraying stems 1.0 to 5.9 in. dbh or injecting stems ≥6.0 in. dbh. Average application times for the injection and basal spray applications of 1.0- to 5.9-in. stems were 2.7 man-hr/ac and 1.97 man-hr/ac, respectively, compared to the 10.3 man-hrs/ac required for the basal spray application of the 2-ft tall to 0.9-in. dbh stems. Average stem densities in the 2-ft tall to 0.9-in. dbh basal spray application (3,743/ac) exceeded the 1,000 stem/acre upper limit recommended by Zedaker (1986) where foliar sprays become more efficient.

Because average stem size varied with application, the number of treated stems and basal area varied greatly among applications. Stem size averaged 8.8 in. dbh in the injection application and 3.0 in. dbh in the 1.0- to 5.9-in. dbh basal spray application. The large difference in treated stem density (3,347/ac) between the two basal spray applications probably accounted for most of the differences in application time. The fewest number of stems was treated in

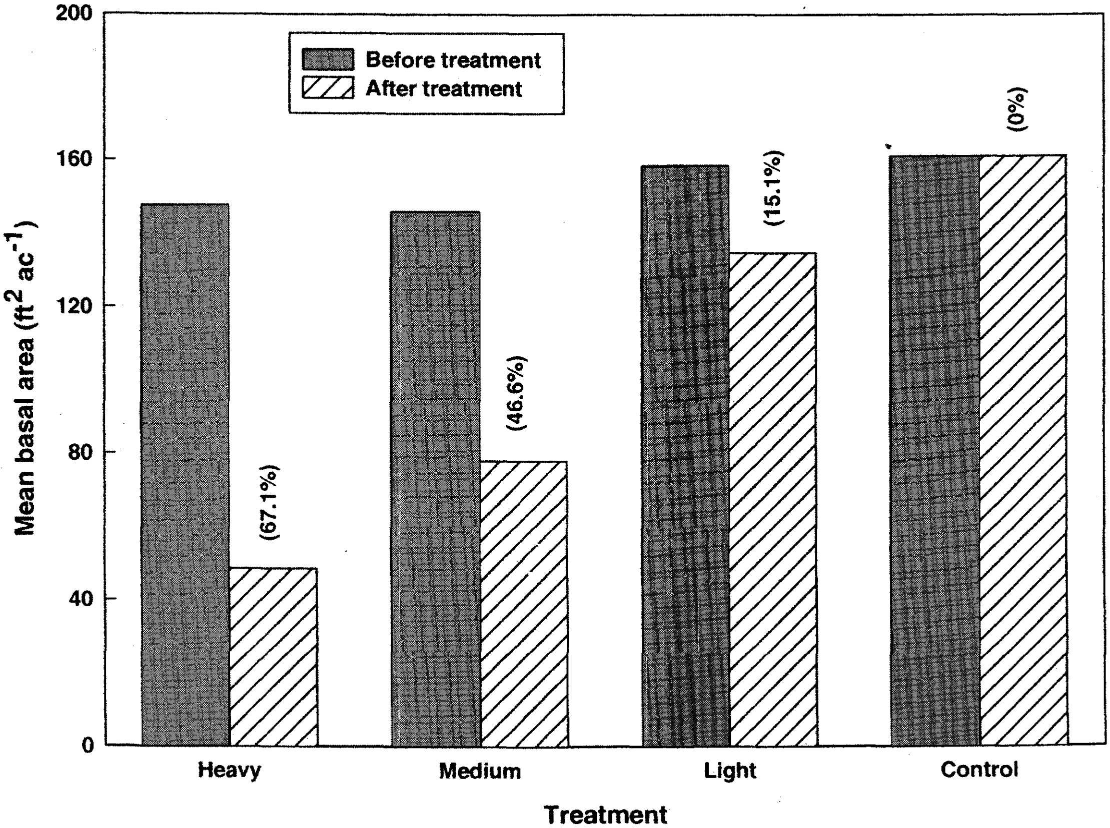


Figure 2. Basal area (ft^2) before and after treatment. The numbers in parentheses are percent reductions in basal area.

the injection application (159/ac) but because trees were larger, treated basal area (71.24 ft^2/ac) was highest for that application.

The higher production rate (stems/hr) for the basal spray application of the 2-ft tall to 0.9-in. dbh stems was attributed to smaller stem size and reduced travel time between the denser stems. The 201-stems/hr production rate and 1.97-man-hr/ac treatment time for the basal spray application of the 1.0- to 5.9-in. dbh stems compares favorably with the production rate of 162 stems/hr and treatment time of 1.6 man-hr/ac reported by Trimble and Wendel (1966). They were basal spraying 1.0- to 5.0-in. dbh stems in a 13.1-ac cutover area in central West Virginia using 2.5-gal hand-pumped sprayers.

Basal area treated per hour was highest for the injection application method. Average production rates for the injection applications (26.39 ft^2/hr) were more than double that for the basal spray application of the 1.0- to 5.9-in. dbh stems. These results agree closely with the basal area production rate of 25 ft^2/hr presented by Wiltrout (1976) for the hack-and-squirt injection method. They are also consistent with Kochenderfer et al. (2001), who reported injection production rates of 70 stems/hr and 15.3 ft^2/hr of treated basal area in crop tree release treatments.

Average Cost

Average costs of the application methods used in this study are shown in Table 3. Note that these costs only include chemical, carrier, and hourly labor costs and do not include travel time, chemical mixing, and other operational costs. The volumes of herbicide solution used varied greatly among applications. The injection applications required the least volume at 0.55 gal/ac. The basal spray (1.0- to 5.9-in. dbh stems) application used 5.12 gal/ac or 0.541 fl oz. (16 ml) per inch of dbh, which is nine times greater than the 0.051 fl oz (1.5 ml) of solution used per inch of dbh in the injection applications. The largest volume of solution, 10.71 gal/ac or 0.372 fl oz. (11 ml) per stem, was used in the basal spray application of the 2-ft tall to 0.9-in. dbh stems, 19 times the volume used in the injection applications.

Table 2. Average production rates for the injection and basal spray application methods.

Application method	Treatment time (man-hr/ac)	Stems treated (no./ac)	Basal area treated (ft^2/ac)	Stem treatment rate (no./hr)	Basal area treatment rate (ft^2/hr)
Injection ($\geq$6.0-in. dbh stems)	2.70	159	71.24	59	26.39
Basal spray (1- to 5.9-in. dbh stems)	1.97	396	24.16	201	12.26
Basal spray (2-ft tall to 0.9-in. dbh stems)	10.33	3,743	–	362	–

Table 3. Average cost of the injection and basal spray application methods. Costs are based on \$44.96/gal for Accord, \$78.07/gal for Garlon 4, \$4.48/gal for Hy-grade I (oil carrier), and \$10.00/hr for labor.

Application method	Volume of herbicide solution (gal/ac)	Chemical and carrier cost (\$/ac)	Labor cost (\$/ac)	Chemical and labor cost (\$/ac)
Injection (≥6.0-in. dbh stems)	0.55	12.26	27.02	39.28
Basal spray (1.0- to 5.9-in. dbh stems)	5.12	60.60	19.72	80.32
Basal spray (2-ft tall to 0.9-in. dbh stems)	10.71	126.76	103.33	230.09

Average herbicide solution costs ranged from \$12.26/ac to \$126.76/ac for the injection and basal spray application methods, respectively. Solution costs for the basal spray application, which included the 2-ft tall to 0.9-in. dbh stems, cost twice as much as basal spraying 1.0- to 5.9-in. dbh stems and 10 times more than the injection application. These costs largely reflect the greater volumes of solution required for the basal spray application.

Herbicide solution costs are a very important consideration in basal spray applications. Herbicide solution costs accounted for 75% (\$60.60/ac) of the total cost of the 1.0- to 5.9-in. dbh basal spray application and 55% (\$126.76/ac) of the total cost for the 2-ft tall to 0.9-in. dbh basal spray application. Labor costs accounted for 24.6% and 44.9% of total costs for the 1.0- to 5.9 in. dbh and 2-ft tall to 0.9-in. dbh basal spray applications, respectively. Conversely, for the injection application, only 31% (\$12.26/ac) of the total cost was chemical and 69% labor (\$27.02). This is consistent with Kochenderfer et al. (2001), who found chemical solution costs accounted for 57% and 35% of the total cost for basal bark band and injection application methods. Carrier costs using Hy-grade I oil accounted for 41.1% of total basal spray application costs. Using diesel oil (\$1.40/gal) instead of Hy-grade I oil (\$4.48/gal) would have reduced carrier costs of the basal spray application by 68.7% and chemical solution costs by 23.4%. Total application costs ranged from \$39.28/ac for the injection to \$230.09/ac for the basal spray application of the 2-ft tall to 0.9-in. dbh stems.

Application Method Efficacy

Beech accounted for 95% of all stems treated in the study. Beech was the only species that had a large enough sample size to permit statistical inferences within an individual species. Other species treated were red maple (3%), serviceberry (*Amelanchier arborea* Michx. f.) (1%), and striped maple (1%). Almost identical efficacy ratings were observed when all the treated species were analyzed together.

All the application methods were extremely effective at controlling American beech. The hack-and-squirt injection applications using a 50% solution of Accord resulted in an average crown control of 99.98%. The basal spray applications using a 10% solution of Garlon 4 had an average crown control of 98.9%. A one-way ANOVA determined that mean efficacy ratings for both herbicide applications were significantly different than the control plots at the α = 0.01 level. No adverse effects were observed on crop tree species, which was expected because glyphosate and triclopyr have no soil activity.

These results are consistent with past studies where glyphosate was used to control American beech. Kochenderfer et al. (2001) obtained average crown controls ranging from 99.8 to 100% using 65.2% concentrations of glyphosate and applying 0.051 fl oz. (1.5 ml) in incisions made for each inch of diameter. Other studies have had success controlling beech using lower concentrations of glyphosate. Maass (1983) using 0.034 fl oz (1 ml) applied in cuts made 2–3 in. apart found that a 25% glyphosate/water solution effectively controlled beech during the dormant season. Wendel and Kochenderfer (1982) effectively controlled 8- to 24-in. dbh beech during the summer by dispensing 0.068 fl oz (2 ml) of 20% solution into incisions spaced 1.5 in. apart around the bases of trees.

The results of the basal spray application methods are also consistent with past studies. Fears (1980) effectively controlled beech using 4 and 8 lbs. of triclopyr mixed with 100 gal of diesel fuel and spraying the lower 18 in. of the stems. Melichar et al. (1987) used 20–30% concentrations of triclopyr and effectively controlled various hardwoods when spraying the lower 12–15 in. of the stems. These results are not consistent with Kochenderfer et al. (2001), where a 26.3% solution of Garlon 4 in oil only achieved an average crown control of 32%. The differences in efficacy can probably be attributed to the larger volume of solution used in this study. Kochenderfer et al. (2001), using the low-volume bark band treatment method, only used 0.10 fl oz. (3 ml) per inch of dbh to treat a 4.0- to 6.0-in. wide band around stems. In this study, 0.54 fl oz (16 ml) of a 10% solution of Garlon 4 and oil was applied per inch of dbh, completely wetting the lower 15 in. of stems to the point of runoff.

Efficacy of Treatments by Size Classes

Treatment efficacy by size class is shown in Table 4. The basal spray applications were very effective at controlling beech stems less than 1 in. dbh. Almost 100% of beech stems were controlled in the heavy and light treatments using the basal spray applications. In the heavy treatment, 100% of the injected stems ≥6.0 in. dbh were controlled. In the medium injection-only treatment, 52% of the untreated beech stems in the 2-ft tall to 0.9-in. dbh class and 21.5% of untreated beech stems in the 1.0- to 5.9-in. dbh class were also controlled (Table 4). Overall, 41% of untreated stems in the 2-ft tall to 5.9-in. dbh size class were controlled. These results are not consistent with Abrahamson (1983),

Table 4. Initial number of beech stems/ac and percent of stems controlled by various treatments. Heavy treatment included basal spray of 2-ft to 5.9-in. dbh stems and injection of ≥6.0-in. dbh trees. Medium treatment included injection of ≥6.0-in. dbh trees. Light treatment included basal spray of 2-ft tall to 5.9-in. dbh trees.

	Size class								
	2 ft tall to 0.9 in. dbh			1.0–5.9 in. dbh			≥6.0 in. dbh		
Treatment	Initial beech stems (no./ac)	Percent of beech stems controlled (%)	SE (%)	Initial beech stems (no./ac)	Percent of beech stems controlled (%)	SE (%)	Initial beech stems (no./ac)	Percent of beech stems controlled (%)	SE (%)
Heavy	4,125	99.5a*[1]	0.55	465	99.8a	0.69	143	100a	0.73
Medium	3,635	52b	0.58	355	21.6b	0.79	159	100a	0.70
Light	3,360	99a	0.58	305	96.3a	0.85	120	4.5b	0.80
Control	3,540	0.6c	0.59	365	0c	0.77	153	0c	0.71

[1] * = means followed by the same letter are not significantly different at the 0.01 level (experimentwise) using Tukey's HSD.

who reported a 70% reduction in the number of beech root sprouts around individual trees when parent trees were injected with a 50% solution of glyphosate. The different results obtained from the two studies can probably be attributed to two key factors. First, Abrahamson (1983) probably applied more herbicide because he completely frilled the parent trees and applied the solution until it began to run down tree trunks. The actual volumes of herbicide used were not measured. In addition, because only the efficacy of beech stems determined to be root sprouts was measured, higher efficacy ratings would be expected. In the present study, all beech stems 2 ft tall to 0.9 in. dbh were included in the efficacy ratings.

Efficacy of the injection treatments in this study on small beech stems would probably have been greater if all beech stems ≥1 in. dbh had been treated with injection instead of only stems ≥6 in. dbh. Control of these untreated stems is attributed to the translocation of herbicide to them from injected trees through connecting roots. Although beech reproduces from both seed and root sprouts, root sprouting is often the major way beech regenerates (Tubbs and Houston 1990). Data collected on the milacre plots in this study indicated that 97% of advanced beech reproduction was of root sprout origin. Jones and Raynal (1986) reported that most beech root sprouts occur within 26 ft of parent stems and remained attached to the parent root system even after the sprouts reached 10 years of age. They also found that root injury is needed to initiate root sprouting. Glyphosate readily translocates to all actively growing parts of treated plants (Weed Science Society of America 1994). This study demonstrated that it is readily translocated from treated parent stems to attached root sprouts. Unlike glyphosate, triclopyr is not as mobile within treated plants (Zedaker et al. 1994, Esen and Zedaker 1999). Thus, the basal spray applications on stems ≤6.0 in. dbh did not result in control of larger untreated stems.

Treatment Cost

Total application costs for the treatments are summarized in Table 5. The cost of treating the small stems in the 2-ft tall to 0.9-in. dbh class is shown separately for the basal spray applications to emphasize the large economic impact treating these smaller stems has on treatment costs. When the cost of treating stems 2 ft tall to 0.9 in. dbh was excluded, the heavy treatment cost was $131.27/ac, followed by the light treatment at $69.57/ac and the medium treatment at $38.29/ac. When the cost of treating stems 2 ft tall to 0.9 in. dbh is included, the cost of the heavy and light treatments more than triples to $407.57/ac and $253.48/ac, respectively. Loftis (1978), when comparing preharvest herbicide treatments to postharvest felling of undesirable stems, also found the cost of basal spraying small stems <2 in. basal diameter to be prohibitive. A major advantage of the medium injection treatment is the added cost savings of controlling the small untreated beech stems. In the medium treatment, 52%, or 1,895, untreated 2-ft tall to 0.9-in. dbh stems/ac were controlled at no additional cost, while it cost approximately $0.06 per stem to treat stems in this size class in the heavy and light basal spray treatments. Controlling 52% of 2-ft tall to 0.9-in. dbh beech stems on the medium plots would have cost an additional $113.70/ac. In addition to controlling these stems, 21.6% or 80 stems/ac of the

Table 5. Application cost summary by treatments. Heavy treatment included basal spray of 2-ft tall to 5.9-in. dbh stems and injection of ≥6.0-in. dbh trees. Medium treatment included injection of ≥6.0-in. dbh trees. Light treatment included basal spray of 2-ft tall to 5.9-in. dbh trees.

		Excludes 2-ft tall to 0.9-in. dbh stems		Includes 2-ft tall to 0.9-in. dbh stems	
Treatment	Treated basal area (ft^2/ac)	Stems/ac (no.)	Application costs[1] ($/ac)	Stems/ac (no.)	Application costs[1] ($/ac)
Heavy	99	626	131.27	4761	407.57
Medium	68	168	38.29	168	38.29
Light	24	316	69.57	3666	253.48

[1] Cost based on $44.96/gal for Accord, $78.07/gal for Garlon 4, $4.48/gal for Hy-grade I (oil carrier), and $10.00/hr for labor.

beech stems in the 1.0- to 5.9-in. dbh class were also controlled in the medium treatments. It cost approximately \$0.21 per stem to basal spray stems from 1.0 to 5.9 in. dbh, representing an additional cost savings of \$16.80/ac. As a result, \$130.50/ac worth of additional control was obtained with the medium treatment at no cost. Loftis (1985) recommended injecting undesirable stems with basal diameters >2.0 in. instead of postharvest felling. Cost data collected from the injection treatments in the study indicated it cost \$0.028 per inch of dbh treated. Projecting this cost to include stems ≥1.0 in. dbh showed that it would cost \$71.21/ac to inject all beech stems 1.0 in. and larger. This cost estimate is consistent with Loftis (1985), who reported injection application costs of \$50–70/ac. The authors believe that injection of all beech stems ≥1.0 in. dbh with a 50% solution of glyphosate would distribute enough herbicide to give adequate control of most existing beech root sprouts.

Management Implications

The manual herbicide application methods used in this study are target specific and applicable for use in steep topography by small nonindustrial landowners. They provide a flexible tool that land managers can use to accomplish a variety of vegetation management objectives. The herbicides used in this study were nonrestricted use herbicides that can be used to control a wide range of common species in Appalachia.

The hack-and-squirt injection method is the cheapest and most target-specific way to control stems ≥1.0 in. dbh. Because small (e.g., 1.0-in. dbh) stems are so flexible, rather than make incisions, it is easier to bend over and partially sever them at waist height, then treat the exposed surface. When applied to similar-sized American beech trees and using glyphosate dosage rates comparable to those used in this study, injection has the added advantage of controlling about half of existing beech stems <1.0 in. dbh and 21.6% of those 1.0–5.9 in. dbh. A disadvantage of injection is that its effective use in the Appalachians is restricted to the growing season period between June 1-Nov. 1, limiting application time to only 5 months of the year. Experience and herbicide label recommendations indicate that tree injection during periods of sap flow is largely ineffective. Although detailed records are not available, observations made by the authors near the study area indicate that sap flow frequently occurs between Nov. 1 and leaf out in this region of the Appalachians. It is especially prevalent in black birch (*Betula lenta* L.) and the maples (*Acer* spp.), but also occurs in other species. Basal sprouting has been observed on some top-killed striped maple and red maple trees injected with 50% solutions of Accord near the study area. In instances where densities of basal sprouts are high, they could present sufficient competition that would require follow-up foliar treatment.

Volume requirements for the various application methods are important cost and labor considerations. For example, 1.5 gal of solution is enough for an entire day of tree injection by one worker and this small volume can easily be carried a considerable distance. Solution requirements for basal spray applications are much higher and almost require machine access to treatment sites to transport the large quantities of solution.

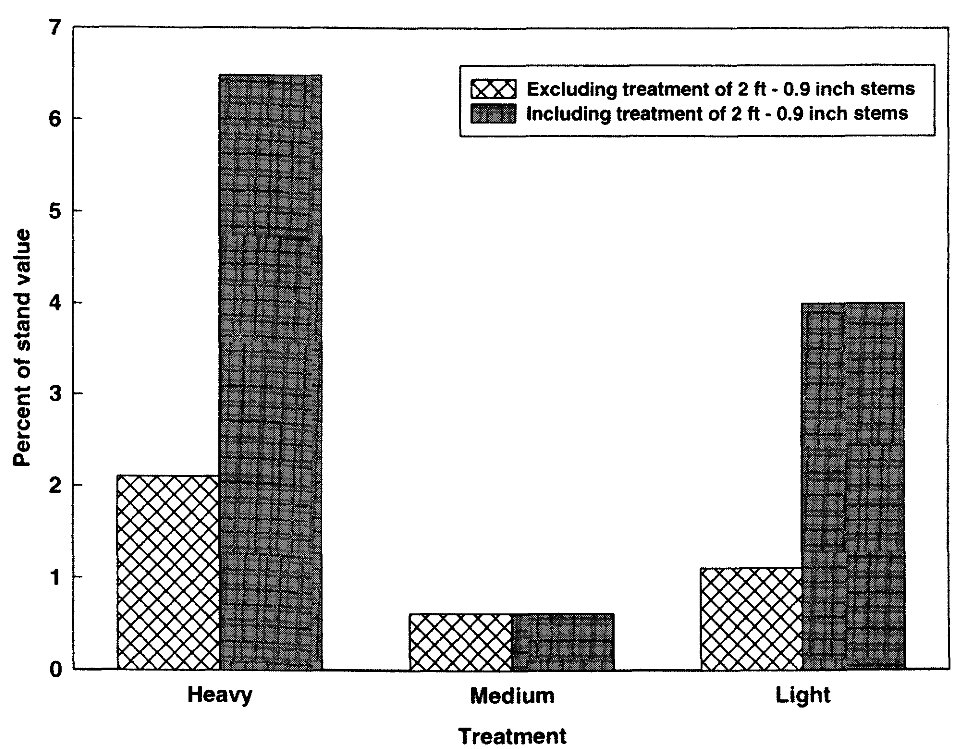


Figure 3. Treatment costs expressed as a percentage of total stand value.

Basal spray applications are more costly but are better adapted for treating small stems. Unlike the injection method, basal spraying is not restricted to growing season application. The only critical label requirements are that applications be made when root collars are exposed and stems are dry. Another advantage is that basal sprouting has not been observed on maple species basal sprayed with a 10% solution of Garlon 4. Experience near this study site indicates that when basal spray application methods comparable to those used in this study are followed, a 5% solution of Garlon 4 is effective on thin-barked species like striped maple, beech, and red maple (J.D. Kochenderfer, unpublished observation). Use of the lower concentration would reduce herbicide costs by 50%.

In some cases, using a combination of application methods might be feasible. For example, injection of all undesirable trees ≥1.0 in. dbh and restricting basal spraying to species other than beech with stems <1.0 in. dbh might be more cost-effective, although it would require traversing the treated area twice. Although foliar spraying methods were not evaluated in this study, they are a viable option where numerous small stems are present. Foliar sprays are broadcast treatments and may kill more than the target stems.

Treatment costs expressed as a percentage of total stand value are shown in Figure 3. The heavy treatment represented 2.1% of stand value when the 2-ft tall to 0.9-in. dbh stems were excluded but 6.5% when the small stems were included. The medium injection treatment represented less than 1.0% of total stand value. The light treatment represented 1.1% of total stand value when treatment of the 2-ft tall to 0.9-in. dbh stems was excluded but 4.0% when their treatment cost was included. These comparisons should help land managers make better treatment choices. Failure to invest in preharvest treatments where dense shade-tolerant understories have become established will eventually result in a decline in valuable shade-intolerant species and reduced stand values.

In conclusion, the preharvest herbicide application methods described in this article are applicable over the wide range of forest types and vegetation conditions encountered in the Appalachians. Although costs varied greatly between the various treatments, efficacy of all the application methods was very high. The question that ultimately needs to be answered is what degree of preharvest vegetation control is required under different conditions to regenerate and grow the desired percentages, e.g., 50%, of high-value species. Information obtained in this study will help land managers make more informed vegetation management decisions.

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