
Herbicide Hardwood Crop Tree Release in Central West Virginia

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ABSTRACT: Chemical crop tree release treatments were applied to young hardwood stands at three sites in central West Virginia to evaluate the effectiveness of glyphosate as Accord (41.5% SL), imazapyr as Arsenal AC (53.1% SL) and Chopper (27.6% EC), and triclopyr as Garlon 3A (44.4% triethylamine salt SL), and Garlon 4 (61.6% butoxyethyl ester EC) using hack-and-squirt injection and low volume stem bark band application methods. American beech (*Fagus grandifolia* Ehrh.) was a major competitor to black cherry (*Prunus serotina* Ehrh.) crop trees at each site. The treatments were applied in June and evaluated 12 months after treatment. A numerical rating system ranging from 1 to 7 (0–100% crown affected), which utilized visual symptoms, 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 the Accord, Garlon 3A, and Arsenal AC injection treatments across all study sites. The low volume stem bark band treatments used in this study were not effective. The imazapyr treatments adversely affected several crop trees and are not recommended for hardwood crop tree release. Some crop tree damage was inflicted by the Accord treatments, but when suggested guidelines are followed, Accord is recommended for crop tree release treatments. No crop tree damage was observed in the Garlon 3A treatments. The costs of the injection treatments expressed in dollars/ft² of basal area controlled were as follows: Accord (\$0.91), Garlon 3A (\$1.04), and Arsenal AC (\$0.84). The Northeast Decision Model Stand Inventory Processor using the NE-TWIGS growth simulator was used to predict the future composition and value of projected stands. The stem injection treatments more than doubled projected growth of black cherry basal area. Real rates of return for investment in weed tree control averaged 8.77% for stem injection treatments. This study indicates that chemical crop tree release treatments using stem injection with label recommended solutions of Accord or Garlon 3A are an effective way to increase the future value of Appalachian hardwood stands. *North. J. Appl. For.* 18(2):46–54.

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Most stands in the Appalachian region are harvested using some type of partial cutting system. A recent survey by Fajvan et al. (1998) indicated that some type of diameter-limit cut was used on 80% of the acreage harvested in West Virginia. Repeated partial cutting favors the growth 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.), in contrast to clearcuts, where on good and excellent sites intolerant species such as black cherry (*Prunus serotina* Ehrh.) and yellow-poplar (*Liriodendron tulipifera* L.) will often dominate new stands (Trimble 1965, 1973, Lamson and Smith 1991). In addition to favoring tolerant species, past cutting practices have also left many cull and undesirable trees and are a primary cause of low quality in many immature hardwood stands (McGee 1986). Since beech has historically had a low commercial value, it was commonly left uncut. More valuable trees like black cherry have been heavily cut since the late 1800s. Where seed sources exist, young black cherry seedlings often become established in the vicinity of seed trees, but most only reach a height of 5 or 6 in. and survive 3 or 4 yr under the dense shade of uncut forest stands (Marquis 1990). In stands where large enough canopy open-

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ings were created, and residual undesirable trees were not too dense, some valuable intolerant species like black cherry often survived. Competition to the development of these crop trees originates both from similarly aged weed trees as well as from older residual trees left from past cuttings. Crop tree release is a widely recommended practice to improve species composition and growth rates in many of these young uneven-aged structured stands (Perkey et al. 1993).

Chemical control of competing trees in crop tree release operations has some decided advantages over mechanical control in these types of stands. Since crop tree release often involves controlling large residual trees left after previous cuttings, it provides a way to reduce the risk of excessive residual stand damage. Other studies have shown that felling operations primarily affect trees of smaller sizes (Nyland and Gabriel 1986, Lamson et al. 1985). Chemical control has the advantage of leaving crop trees free from competition for a longer period of time (Wendel and Lamson 1987). The herbicide treatments are also safer for most people to apply than mechanical methods, like chainsaw felling (Howard 1993). Chemical control of undesirable trees also creates standing dead trees, which can provide valuable habitat for wildlife (Moorman et al. 1999).

Herbicides are widely used to control undesirable hardwoods in broadcast applications. However, few trials have been designed to evaluate the efficacy and cost-effectiveness of herbicides and applications that could be used in crop tree release treatments. Since beech is a common competitor to more desirable trees across a wide array of sites in Appalachia, it was the major focus of this research. The primary objective of this study was to evaluate the effectiveness of five different herbicide treatments applied to control American beech in crop tree release treatments. A secondary objective was to compare the cost and effectiveness of two different application techniques, low volume stem bark band and hack-and-squirt. A third objective of this study was to evaluate crop tree growth response to chemical release and by projecting the growth of treated and untreated stands using the NE-TWIGS growth model to evaluate the economic benefits of crop tree release.

Methods

Study Areas

Three study sites were located in the unglaciated Allegheny Mountain region of central West Virginia, near the towns of Parsons, Bayard, and Rupert. The Parsons site is located in the Cove Hardwood Type (Society of American Foresters Type 57). Like most private tracts of land in this area, the complete land use history is not accurately known, but the tract was probably partially cut and burned several times in the past. It was last cut in 1979 to a 12 in. stump diameter limit. Much of the American beech, red maple, and black birch (*Betula lenta* L.) were left uncut. Where residual stand density was low, an adequate number of black cherry and yellow-poplar crop trees became established. Conversely, on areas where a high residual stocking of undesirable species were left, beech and red maple were usually dominant. The predominant soil type is Berks Channery silt loam (loamy-skeletal, mixed, mesic Typic Dystrochrepts) (Losche and Beverage 1967). This soil is strongly acid with a 20 to 40 in. depth to bedrock.

The Bayard study site is located in the Northern Hardwood Type (Society of American Foresters Type 28). This study site was first heavily cut over about 1900 (Fansler 1962) when the stand contained a red spruce (*Picea rubens*) component, then was cut again in about 1965. Evidently this site, like much of the surrounding area, was burned because there are few spruce present in the stands today. There might have been a dense understory of beech present at the time of the second cutting, because the current stand is composed of a very high percentage of beech, with scattered 6 to 10 in. codominant and dominant black cherry. The beech component of this stand consists of larger and older residual trees left from the earlier cuttings, along with a rather dense beech sapling and pole component that occupies much of the study site. The predominant soil type is Dekalb Channery loam (loamy-skeletal, mixed mesic, Typic Dystrochrepts) (Losche and Beverage 1967).

The Rupert study site is also located in the Northern Hardwood Type (Society of American Foresters Type 28). This site was probably first cut over around 1920 and then again in 1969, to a 20 in. stump diameter limit. There are several large cherry stumps scattered on this site, some of which apparently date back to the 1920s harvest. The stand does not appear to have been burned since the first cut, because there are a few scattered large red spruce in the stand along with patches of spruce regeneration in the understory. Black cherry regeneration developed as a result of the second cut, where large enough openings were created in the overstory. The main trees competing with the black cherry crop trees are large residual beech left from earlier cuttings and smaller pole-sized beech. There are also several older cull red maple trees left from earlier cuttings. The predominant soil type is Cookport variant silt loam (fine-loamy, mixed, mesic Aquic Hapludults), which is a very acidic soil characterized by a mottled clay subsoil (Losche and Beverage 1967). Other characteristics of the three study areas are shown in Table 1.

Measurement and Treatment of the Plots

Eighteen 0.10 ac circular plots were located on each of the study sites. Criteria used to select plots were based on the number of beech trees and black cherry crop trees present. An average of 10 beech stems, 2 in. or larger in diameter at breast height (dbh), were required on each 0.10 ac plot in order to do the appropriate statistical analysis (Zedaker et al. 1993). A minimum of two black cherry or yellow-poplar crop trees were also required on a 0.025 ac plot established within the 0.10 ac plot.

Plots were located in areas where site quality appeared consistent, but past harvesting practices made visual site index determinations unreliable (McGee 1982). Actual site indices were determined by felling six dominant black cherry trees on each study area. Heights of felled trees were measured, and age was determined from the tree ring counts on disks collected, both at groundline and at dbh. The groundline age was used to determine the stand age at each site. Individual tree ages were determined by adding 4 yr to the age determined at dbh, as recommended by Auchmoody and Rexrode (1984). This age was applied to site index curves developed by Auchmoody and Rexrode (1984) to determine the average black cherry site index for each study site (Table 1).

Table 1. Characteristics of the three study sites.

	Sites		
	Parsons	Bayard	Rupert
Age since last harvest (yr)	20	33	29
Stand density (trees/ac)*	1,339	1,248	879
Basal area (ft ² /ac)*	95	114	135
Aspect	NW	NW	NE
Elevation (ft)	2,200	3,300	3,960
Ave. annual precipitation (in.)	51	50	57
Site Index [†]	91	75	83
Ave. stand diameter (in.)	4.9	4.8	5.9
Dominant tree species	American beech	American beech	American beech
	Red maple	Red maple	Red maple
	Yellow-poplar	Black cherry	Fire cherry (<i>Prunus pensylvanica</i> L.)
	Black cherry		Black cherry

* all stems 1 in. and larger were measured.

† Black cherry site index base age 50 (Auchmoody and Rexrode 1984).

The average number of crop trees selected on each 0.025 ac plot ranged from 2.2 on the Bayard and Rupert sites to 4.8 in the younger stand on the Parsons site. Crop tree dbh ranged from 2.5 to 10 in. and averaged 5.6 in. The following criteria were used to select the crop trees:

1. Trees had to be a valuable timber species, preferably black cherry or yellow-poplar.
2. Trees had to be at least codominant in crown class.
3. The first 17 ft of the bole had to be clear, straight, and free of forks.
4. No black knot visible on the first 17 ft of the boles of black cherry.
5. Crowns had to be healthy with no grapevines or grapevine damage present.

Almost all the crop trees selected on the Bayard and Rupert sites were black cherry. Black cherry and yellow-poplar each comprised about half the crop trees on the Parsons site.

The crown-touching release criteria developed by Perkey et al. (1993) were used to release the crop trees. All trees interfering with or touching crop trees, except other crop trees, were marked for treatment. Also, all beech trees 2 in. dbh or greater on the 0.10 ac plot were marked for treatment.

All the crop trees and treated trees were permanently marked with a numbered aluminum tag placed at the base of each tree. Crown class and dbh were recorded for all marked trees.

Five herbicide treatments and one control treatment were randomly assigned to the 18 plots at each study site. Each treatment was replicated three times at each study site. The hack-and-squirt injection method and low volume stem bark band method were used to apply the treatments. The herbicides used in the injection treatments were: (1) glyphosate (N-(phosphonomethyl) glycine as Accord 41.5% SL); (2) imazapyr ((+)-2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1 H-imidazol-2-yl]-3-pyridinecarboxylic acid as Arsenal AC (53.1% SL); and (3) triclopyr (3,5,6-trichloro-2-pyridinyloxyacetic acid as Garlon 3A (44.4% triethylamine salt SL). The stem bark band treatments were: (1) triclopyr as Garlon 4 (61.6% butoxyethyl ester EC)); and (2) imazapyr as Chopper

(27.6% EC)). The following concentrations of formulated product were used: Accord (65.2%), Arsenal AC (7.5%), Garlon 3A (50%), Garlon 4 (26.3%), and Chopper (6.3%). These concentrations were determined by using the most expensive injection and stem bark band chemicals at their lowest recommended label rates as reference standards. The concentrations of the other chemicals were adjusted so that the chemical solution costs were the same within each treatment. This procedure enabled the chemicals to be compared on an equal-cost basis.

In the injection treatments, 0.051 fl oz (1.5 ml) of solution was used per inch of dbh. The injection incisions were made at waist height using a hatchet with a 1.75 in. bit. A Ben Meadows herbicide gun was used to dispense the herbicide solution. The low volume stem bark band treatment used 0.101 fl oz (3 ml) of solution per inch of dbh applied at waist height. The herbicide concentration used for basal applications are equivalent to Chopper thinline and the Garlon 4 streamline label recommendations. Although larger stems may have had less total volume applied than the labels imply, smaller stems would have been overdosed. The rationale for using this low volume stem bark band treatment was that it would be effective, since most of the trees being treated were small (61% less than 6 in. dbh) and were thin-barked species (Zedaker 1986). A constant volume per inch of dbh was necessary to ensure similar cost per unit of basal area treated. A meterjet herbicide gun connected to a backpack sprayer was used to dispense the herbicide used in the stem bark band treatments. Hygrade EC oil was used as the carrier for the basal spray treatments, and water was the carrier for all the injection treatments. All plots were treated after full leaf-out in June 1998. The amount of time it took to apply treatments and the actual volumes of herbicide used were recorded for each plot.

Efficacy Evaluations

A numerical rating system ranging from 1 to 7 (0–100% crown affected), similar to one used by Memmer and Maass (1979) using visual symptoms, was used to evaluate the efficacy of each treatment. In addition, GRS densiometer was used to estimate forest canopy density (%) to quantify the amount of crown control. There was a

close relationship ($R^2 = 0.85$, $P = 0.0001$) between the densiometer readings and the ocular estimates of crown density. Three different observers rated the plots at each study site. The mean ratings for each plot showed no distinct bias among observers, thus no adjustments were made for any of the ratings.

The treatments were evaluated in June 1999, 12 months after treatment. A mean (three plots) treatment numerical efficacy rating was determined for beech and all species combined at each study site. Beech and all species combined were also analyzed separately by size classes: saplings (1.0–4.9 in. dbh), poles (5.0–10.9 in. dbh), and sawtimber (11.0 in. dbh and larger) in order to determine if tree size affected efficacy ratings. Trees with efficacy ratings of 5.0 or higher (75% crown necrotic) were considered controlled. 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). The relationship between the different herbicides, type of application, and efficacy ratings were analyzed by means of a one-way analysis of variance with an incomplete random factorial design with three observations per treatment. Basal area (ft²) and total treatment costs were used as variables to compute the cost-effectiveness of each treatment. This data was summarized by treatments (three plots) on each study area. The cost-effectiveness of each treatment was determined using the following formula:

$$CE = \frac{TC}{(TBAT - BANC)}$$

where

Cost effectiveness (CE) = Average cost to effectively control each ft² of basal area.

Total treatment costs (TC) = Total costs include labor and chemicals.

Total basal area treated (TBAT) = Total basal area in ft² treated.

Basal area not controlled (BANC) = Basal area in ft² with efficacy ratings less than 5.0 (75% crown control).

Crop Tree Release Evaluations

The cost and success of the crop tree release treatments were determined first by computing the average basal area treated per crop tree and the average 12 month efficacy rating of the treated competing trees around each crop tree. The percentage of crop trees successfully released was determined by computing a release rating for each crop tree. Since several of the treated trees were competing with more than one crop tree, the number of competing trees and their efficacy ratings were prorated among two or more trees. A crop tree was considered successfully released if its competing trees had an average efficacy rating of 5.0 (75% crown control) or higher. The release cost per crop tree was computed by multiplying the basal area treated to release it by the cost-effectiveness (\$/ft² BAC) of each herbicide treatment.

Growth Projections

The Northeast Decision Model Stand Inventory Processor (NED/SIPS) (Simpson et al. 1995) running the NE-TWIGS growth simulator (Hilt and Teck 1989, Teck 1990) was used to project the species compositional changes based on stand basal area at each study site to the end of an 80 yr rotation. Merchantable heights used in NED were obtained by using a taper function developed by Wiant and Yandle (1983) that uses total height and mean stand diameters to calculate merchantable height for any given merchantable diameter (dob). Estimates of total tree heights at age 80 were obtained from Auchmoody and Rexrode's (1984) site index curves, and mean stand diameters were obtained from NED projections (Simpson et al. 1995). Growth of the crop trees, their competing trees, and other codominant trees on the 0.025 ac plots were projected to determine the proportion of black cherry, beech, yellow-poplar, cucumbertree (*Magnolia accuminata* L.), sugar maple, and red maple in both the treated and untreated stands. Real rates of return were then determined using the following formula:

$$r = \left(\sqrt[t]{(svt - svnt) / c} \right) - 1$$

where

r = real rate of return

t = time until the end of the rotation

svt = projected stand value with treatment

$svnt$ = projected stand value without treatment

c = release cost per acre

Sawtimber stumpage values used in this analysis were obtained from timber sale bids received for comparable timber in 1997 on the Monongahela National Forest in the vicinity of the study area (USDA 1997). The low volume stem bark band treatments were excluded from the growth analysis because they were ineffective, and problems were encountered with dispensing consistent volumes of solution.

Results and Discussion

Applications

The hack-and-squirt treatments required more time to apply than the low volume stem bark band treatments (Table 2). The average application time was 4.6 hr/ac for the hack-and-squirt treatments compared to 2.8 hr/ac for the low volume stem bark band treatments. The average number of stems and basal area treated per plot were very similar for both treatments. The low volume stem bark band was the most efficient treatment; 44% more stems and 38% more basal area were treated per hour using this application method. Labor and chemical costs accounted for an average of 65 and 35%, respectively, of total treatment costs for the hack-and-squirt method, compared to 43 and 57% for the low volume stem bark band method. Total treatment costs (labor and chemical) for both application methods were almost identical, averaging about \$0.90/ft² of basal area treated (Table 2). The higher labor costs for the hack-and-squirt treatment were offset by the higher chemical costs for the stem bark band treatments.

Table 2. Mean application rates of the low volume basal spray and hack-and-squirt treatments for three sites in West Virginia.

Application type	Treatment time (hr/ac)	No. of stems treated/ac	Basal area treated (ft ² /ac)	No. of stems treated/hr	Basal area treated per hour (ft ²)	Treatment cost per ft ² of basal area treated (\$/ft ²)
Hack-and-squirt	4.6a*	306a	64a	70a	15.3a	0.91
Low-volume stem bark band	2.8b	326a	63a	124b	24.9b	0.89

* Means within columns followed by the same letter are not significantly different at the 0.05 level (Experimentwise) using Tukey's HSD

One reason why the low volume stem bark band treatments were much more productive was that the plots were fairly small, so running out of solution was not a problem. It should also be noted that the production times shown in Table 2 only include actual plot treatment times. They do not include time for items such as travel from plot to plot and chemical mixing.

Wiltout (1976), evaluating treatment costs in Indiana, found that production rates for the hack-and-squirt method were almost twice as high as those determined for this study. His production rates were 217 stems/hr and 25 ft² of basal area/hr. These differences can probably be attributed to the inexperienced crew used to treat the plots in our study. Results of this study are consistent with those of Groninger et al. (1998), who found that basal spray was more productive than injection or chainsaw felling.

Treatment Efficacy on Treated Trees

Beech accounted for 77% of all the trees treated in the study. It was the only species that had a large enough sample size to permit statistical inferences within an individual species. Other species treated were black cherry (11%), red maple (4%), yellow-poplar (1%), and black birch (1%). Almost identical treatment efficacy ratings were observed when all the treated species were analyzed together.

The injection treatments had the highest efficacy ratings 12 months after treatment (Table 3). All three injection treatments had average crown control ranging from 99 to 100% across all three study areas and were significantly different than the other treatments at the $\alpha = 0.05$ level. The low volume stem bark band treatments proved to be largely ineffective across all study sites. The effectiveness of the Garlon 4 treatments at the Bayard site (69%) was attributed to an error made in dispensing the herbicide solution at that site. Almost twice as much Garlon 4 was used per inch of dbh at that site. Average crown control for the Garlon 4 treatment ranged from 3% at Rupert to 70% at the Bayard study site. Chopper crown control ranged from 1% at Parsons to 22% at Bayard. The increased efficacy of Chopper at this site can also probably be attributed to a solution dispensing

error; approximately 35% more Chopper solution was applied per inch of dbh than prescribed.

Few studies that evaluated the effectiveness of herbicides in hardwood crop tree release treatments have been done; however, other studies have shown tree injection treatments to be effective on American beech. Holt (1981), working in an Indiana forest, found that a 25% solution of glyphosate and water was not effective at controlling beech between 8 and 18 in. dbh, but that 100% solutions of glyphosate were highly effective. Maass (1983) found that a 25% glyphosate/water solution effectively controlled beech during the dormant season, when 0.034 fl oz (1 ml) was applied in cuts made 2 to 3 in. apart. These results are consistent with Wendel and Kochenderfer (1982), who effectively controlled 8 to 24 in. dbh beech during the summer using a 20% solution of glyphosate, dispensing 0.068 fl oz (2 ml) of solution into incisions spaced 1.5 in. apart around the bases of trees. Ostrofsky and McCormack (1986) applied 0.017 fl oz (0.5 ml) of 100% glyphosate solution per inch of dbh to completely frilled beech. Complete crown control of beech was achieved, and the number of sprouts was reduced by 85%.

Past studies using triclopyr in injection treatments have also shown inconsistencies. Holt (1981) only controlled 61% of the treated trees when using a 25% solution of triclopyr and water. Maass (1983) found a 33% solution of triclopyr to be effective when 0.034 fl oz (1 ml) of solution was injected every 1 to 2 in. around the stem. Other studies by Arbrahamson (1983) and Ostrofsky and McCormack (1986) demonstrated that beech could be effectively controlled with triclopyr. In both studies, a complete frill using 100 and 50% solutions of triclopyr, respectively, resulted in greater than 90% crown kill.

Miller (1992) rated beech as susceptible to Arsenal AC, but little research has been done using Arsenal to control American beech. Yeiser and Rhodenbaugh (1994) used Arsenal AC on an assortment of hardwoods in Arkansas, including blackgum (*Nyssa sylvatica* Marsh.), red maple, and black cherry. Their injection treatments consisted of making one incision per inch of dbh and applying 0.051 fl oz (1.5 ml) of solution per incision using 10, 50, and 100% concentrations

Table 3. Mean treatment efficacy ratings for beech 12 months after treatment for the three study sites.

Treatment/chemical	Study sites		
	Parsons	Bayard	Rupert
	(% crown control).....		
Stem injection			
Accord	99.8a	100.0a	100.0a
Garlon 3A	100.0a	100.0a	99.9a
Arsenal AC	100.0a	100.0a	99.4a
Low volume stem bark band			
Garlon 4	25.0b	69.6b	2.5b
Chopper	0.9c	21.9c	1.1b
Control	0.0c	0.0d	0.1b

* Means within sites followed by the same letter are not significantly different at the 0.05 level (Experimentwise) using Tukey's HSD.

of Arsenal AC. The 10% concentration of Arsenal AC was significantly less effective than the 50 and 100% concentrations. However, Nelson et al. (1993) injected 10, 50, and 100% solutions of Arsenal AC into incisions spaced every 4 in. of dbh and achieved nearly 100% crown reduction for all three concentrations on black cherry, blackgum, red maple, and hickory (*Carya* spp.).

There was no distinct trend observed in injection efficacy between sapling (1.0–4.9 in. dbh), pole (5.0–10.9 in. dbh), and sawtimber (11.0 in. dbh and greater) sized trees across the three study sites (data not shown). Efficacy ratings averaged almost 100% across all size classes. Although most of the trees treated were in the smaller size classes, 10% (64 trees) ranged in size from 11 to 23 in. dbh. These results differ from Holt (1981), who observed that large beech trees (> 14 in. dbh) were harder to control than small beech trees. Efficacy ratings were too low for the stem bark band treatments to detect any consistent trends among size classes.

The efficacy of the low volume stem bark band treatments were not consistent with Fears (1980), who effectively controlled beech using 4 and 8 lb of triclopyr mixed with 100 gal of diesel fuel and spraying the lower 18 in. of the stems. The differences in treatment effects can probably be attributed to the larger volume of solution used by Fears (1980). It was often difficult to treat a continuous band around stems with the volumes of solution [0.101 fl oz (3 ml) per inch of diameter] used in this study. Melichar et al. (1987) also used 20–30% concentrations of triclopyr and effectively controlled various hardwoods when spraying the lower 12–15 in. of the stems. The results of the Chopper treatment on beech in this study are not consistent with past studies on other hardwood species. Weidenfeller et al. (1989) found that 5 and 7% solutions of Chopper gave good control of red maple, red oak (*Quercus rubra* L.), and black locust (*Robinia pseudoacacia* L.). Ezell et al. (1996) also found Chopper to be an effective basal treatment controlling an assortment of hardwoods. In both studies, the lower 12–18 in. of the stems were wetted. The volume of solution (0.101 fl oz per inch of dbh) used in the low volume stem bark band treatments in our study was only enough to wet a 6 in. band around the tree stems. The volume of solution required to saturate the lower 6–10 in. of the treated stems was several times greater than the amount of solution used in this study. This is probably the major reason why the results presented here conflict with past studies on low volume stem bark band treatments. The treated trees in this study ranged from 2 to 23 in., averaging 5.2 in.

Crop Tree Damage

Damage to crop trees was observed during the 12 month treatment evaluation. At the Rupert and Parsons study sites, only minor damage was recorded: one crop tree was killed at each site by the Chopper and Arsenal AC (imazapyr) treatments. However, at the Bayard site, significantly higher crop tree damage was found. Four of the six crop trees (66%) were killed by the Arsenal AC treatments; the four dead trees, along with crown damage in the remaining crop trees, resulted in a total average crown control of 75%. Crop trees on the Accord and Chopper plots at this site also received minor damage, resulting in average crown controls of 11.0 and 7.5 % respectively.

Observing crop tree damage 12 months after treatment with Arsenal AC was not completely unexpected. Imazapyr exhibits soil activity (Anderson 1996) and can be absorbed through the roots of plants outside the treated areas (USDA 1989). Trees normally do not show the full effects of this herbicide until several months after treatment. However, the extent of the crop tree damage was unexpected because tree injection is target-specific, and lower application rates than intended (0.029 fl oz/in. of dbh) were used in the treatments at this site. The soils on the Bayard study site have lower proportions of clay and organic matter than soils on the other study sites. Since herbicide activity and movement are greater in soils with lower clay and organic matter contents (Anderson 1996), the greater herbicide activity on the Bayard site might be due to the coarser textured soils present on that site. Although sprout control was not evaluated in this study, beech root sprout mortality in the plots treated with Arsenal AC and Accord also appeared to be higher on the Bayard site.

The crop tree damage observed on the plots treated with Accord was not consistent with the results of Wendel and Lamson (1987), who reported no adverse effects on hardwood crop trees after injection release treatments. However, they only used a 20% solution of glyphosate, while a 65% solution was used in this study. Damage from the Accord treatments only occurred when the same species as the crop trees were treated within 4 ft of crop trees. When different species were treated adjacent to crop trees, no damage was observed with the glyphosate treatment. Since glyphosate binds tightly to soil particles and has little residual soil activity, translocation of glyphosate probably occurred through root grafts. In these older stands it was not possible to determine if the treated trees and crop trees were sprouts from the same stump. No crop tree damage was observed on any plots treated with Garlon 3A. Stein (1992) used a 50% solution of triclopyr for stem injection and an 8% solution for basal spray to thin oak stump sprouts and only minor damage was inflicted on the crop trees, which is consistent with these study results.

Treatment Cost Effectiveness

The mean cost effectiveness for the treatments expressed as cost per ft² of basal area controlled (\$/ft² BAC) is shown in Table 4. Cost effectiveness shows the relationship between total treatment costs and the amount of basal area actually controlled. Lower cost effectiveness reflects the most efficient treatments. For a given set of costs, as the

Table 4. Cost effectiveness expressed as cost per ft² of basal area controlled (\$/ft² BAC) for all treatments and study sites (cost based on 12 month evaluations).

Chemical	Study sites		
	Parsons	Bayard	Rupert
Injection			
Accord	0.74	1.20	0.80
Garlon 3A	0.92	1.32	0.88
Arsenal AC	1.14	0.70	0.68
Low volume stem bark band			
Garlon 4	7.00	3.37	34.80
Chopper	10.58	4.92	7.71

* Cost based on the following prices per gallon: Accord (\$52.40), Garlon 3A (\$68.60), Arsenal AC (\$453.12), Garlon 4 (\$83.40), and Chopper (\$332.80)(Prices obtained from CWC Chemical Cloverdale, Virginia—1998). Cost of labor used was \$8.00/hr.

Table 5. Effectiveness of the crop tree release treatments across all study sites.

Treatment/chemical	Ave. no. of crop trees (trees/ac)	Ave. BA treated/crop tree (ft ²)	Ave. efficacy rating of competing trees (%)	Ave. no. of treated competing trees/crop tree	Crop trees released* (%)	Ave. cost/crop tree released (\$)	Ave. release cost/ac
Stem injection							
Accord	111	1.29	99.9	4	100	1.09	120.99
Garlon 3A	124	1.10	99.9	4	100	1.10	136.40
Arsenal AC	133	1.02	100.0	5	100	0.77	102.41
Low volume stem bark band							
Garlon 4	129	0.82	30.1	4	10	15.99	2,062.71
Chopper	107	1.30	37.2	4	13	10.00	1,070.00
Control	133	1.10	0.0	5	0	—	—

* No. of crop trees with an competing tree average efficacy rating (%) greater than 75 divided by the total number of crop trees for that treatment.

amount of treated basal area not controlled increased, the cost effectiveness of the treatments also increased. Accord, Garlon 3A, and Arsenal AC were the most cost-effective treatments across all sites. Although the low volume stem bark band treatments were more productive in terms of the number of stems treated per hour (Table 2), they were not very cost effective. This demonstrates the importance of integrating treatment efficacy into cost evaluations. The mean cost effectiveness for Arsenal AC at the Bayard site was lower than that of Accord or Garlon 3A, because the amount of herbicide used for the Arsenal AC treatment at that site averaged only 0.029 fl oz (0.86 ml) per incision instead of the intended rate of 0.051 fl oz (1.5 ml) per incision. This decreased the chemical cost for that treatment. The Arsenal AC cost effectiveness was very low (0.68 \$/ft² BAC) at the Rupert site due to a very high rate of control and a low labor cost at that site.

Crop Tree Release Effectiveness

As expected, the treatments with the highest efficacy ratings (Accord, Garlon 3A, and Arsenal AC) were most successful in releasing crop trees (Table 5). All three of these injection treatments released 100% of the crop trees. The low volume stem bark band treatments, which had low efficacy ratings, also resulted in low percentages of crop trees being released. The average efficacy ratings for the competing trees also match up well with the percentage of crop trees released. The Accord, Garlon 3A, and Arsenal AC treatments had efficacy ratings of 100%, and all these treatments released 100% of the crop trees. The average efficacy rating for the competing trees on the low volume stem bark band treatments only averaged 34%, resulting in only 12% of the crop trees being successfully released.

The average basal area treated per crop tree was similar, averaging 1.11 ft² across all study sites. It was comprised of about 50% beech, 33% black cherry, and 17% assorted hardwoods such as yellow-poplar, cucumbertree, and red maple. The release costs averaged \$0.99/crop tree for the injection treatments and \$13.00 for the low volume stem bark band treatments. The primary factors influencing these costs were the average amount of basal area treated per crop tree and the cost effectiveness of the treatments. The poor cost effectiveness of the low volume stem bark band treatments resulted in very high release costs per tree. The release cost per acre was determined by applying the average individual crop tree release costs to the average number of crop trees per acre. Release costs averaged \$119.93/ac for the injection treatments and 1566.36/ac for the low volume stem bark band

treatments. The average number of crop trees per acre at the Bayard and Rupert sites generally fell within the 50 to 100 crop trees per acre recommended by Perkey et al. (1993). But at the Parsons site, more crop trees were left because they were younger, and response to the release treatment was more questionable for some of the crop trees.

The average release costs per crop tree (\$0.99) for the injection treatments in this study was higher than that found by Miller (1984) (\$0.61/tree) or Stein (1992), whose release costs averaged \$0.34 per crop tree. A major reason for these cost differences might be related to stand structure. The previous studies were done in younger even-aged stands with smaller stems. The structures of the stands used in this study were much different, because they were chosen to represent the complex uneven-aged stands with numerous large residual trees common on private forestland in the Appalachians. The presence of these large residual trees eliminated chainsaw felling as a viable option because of residual stand damage considerations. Treatment of these larger residual trees increased the basal area treated per crop tree, treatment times, and chemical requirements. The relatively large number of crop trees released per acre, especially at the Parsons site, use of inexperienced crews, and to a lesser extent, the amount of basal area treated per crop tree, also influenced treatment costs.

Crop Tree Growth Responses

A one-way analysis of variance, using dbh as a covariant, indicated that there were significant crop tree diameter growth response differences among treatments at all three study sites after two growing seasons (Table 6). At the Parsons and Rupert sites, the injection treatments had significantly more diameter growth than the control treatments. Mortality at the Bayard site, especially on the plots treated with Arsenal AC and Accord,

Table 6. Growth responses of the crop trees expressed as the growth increment increase (in.) over the first two growing seasons after injection treatment.

Chemical	Study sites		
	Parsons	Bayard	Rupert
	(in.)		
Accord	0.67a*	0.33b	0.80a
Garlon 3A	0.63a	0.51a	0.64a
Arsenal AC	0.57a	0.23b	0.71a
Control	0.31b	0.35b	0.55b

* Means within sites followed by the same letter are not significantly different at the 0.05 level (Experimentwise) using Tukey's HSD.

Table 7. Average projected species composition (% basal area ft²) for injection treatments across all study sites.

Treatment/chemical	Without treatment					With treatment				
	Black cherry	Yellow-poplar*	Beech	Maple	Others	Black cherry	Yellow-poplar	Beech	Maple	Others
	(%)									
Stem injection										
Accord	29	2	62	4	3	67	16	7	7	3
Garlon 3A	35	1	57	3	4	74	13	11	2	0
Arsenal AC	35	5	48	5	7	77	18	0	1	4
Control	27	0	52	14	7	27	0	52	14	7

* Includes cucumbertree.

reduced mean growth, making the Garlon 3A treatment significantly different than all other treatments. Early response data are often lacking in crop tree release studies because remeasurements are commonly made at 5 yr intervals (Lamson and Smith 1989, Wendel and Lamson 1987, Miller 2000). Trimble (1973), working in a 7-yr-old clearcut, remeasured crop tree diameters after 2 yr and found no significant differences between released and control stems. Most crop tree release studies have been done in even-aged stands where competing trees were the same age and approximately the same size. The rapid response observed in this study may be attributed to a more complete release because not only were touching trees treated, but numerous large residual trees that were also interfering with the growth of crop trees were controlled. Increases in diameter growth have been shown to be related to the degree of release in other studies (Lamson et al. 1990, Ward 1995). The chemical treatments used in this study also reduced root competition, which may have contributed to the rapid response.

Treatment Effects on Future Stand Composition

Projected species compositions (% basal area ft²) were altered dramatically by release (Table 7). Crop tree release is expected to substantially increase future stand values because of the large differences in average sawtimber stumpage values between black cherry (\$800/mbf) and beech (\$30/mbf). The injection treatments decreased the average percentage of beech basal area from 56% to 6% across all study sites. The average percentage of black cherry basal area was increased from 33% in the untreated stands to 73% in the treated stands across all study sites. While growth rates and stand quality can be enhanced by crop tree release, these factors are not as important as long-term changes in species composition (Zedaker 1986). The wide disparity in commercial species value in Appalachian forests make species composition a key consideration in vegetation management. The real rate of return for investments in crop tree release averaged 8.77% for the injection treatments (Table 8). The projected stand values and rates of return were lower at the Parsons site. This was attributed to the projected increase in volumes of yellow-poplar and cucumbertree, lower value species, higher release cost per acre, and a longer time until

Table 8. Projected real rates of return* for injection treatments at all three study sites.

Treatment	Parsons	Bayard	Rupert
	(%)		
Stem injection			
Accord	6.90	10.30	9.38
Garlon 3A	7.07	9.80	8.82
Arsenal AC	7.55	8.51	10.56

* Based on an 80 yr rotation and the following stumpage prices: black cherry—\$800/mbf; yellow-poplar—\$250/mbf; maple—\$250/mbf; and beech—\$30/mbf.

harvest (60 yr) at that site compared to 51 and 47 yr at the Rupert and Bayard sites, respectively.

Conclusions

Stem injection treatments of Accord, Garlon 3A, and Arsenal AC at the concentrations used in this study were very effective at controlling American beech and other assorted hardwoods. The stem bark band treatments were ineffective at controlling beech or the other assorted hardwoods. The Accord, Garlon 3A, and Arsenal AC treatments all resulted in 100% of the crop trees being released. The Arsenal AC treatment was the only treatment that damaged large numbers of crop trees and is not recommended for hardwood crop tree release. More research is needed to determine if lower concentrations of Arsenal AC can be used without damaging crop trees while at the same time controlling undesirable competing trees. The Accord treatments also damaged crop trees in two instances when competing trees of the same species were treated close to them. Accord should not be used to treat competing stump sprouts originating from the same stump as crop trees, or to control competing trees closer than 5 ft to trees of the same species as crop trees. A 50% solution of Garlon 3A will result in less damage to hardwood crop trees than the other treatments evaluated in this study. Crop tree damage from both the Arsenal AC and Accord treatments may be more prevalent on the coarser textured soils.

The cost effectiveness of each treatment was directly related to the amount of basal area controlled. The stem bark band treatments were more productive but much less effective than the injection treatments. This analysis has shown that the effective control of undesirable low-value species such as beech can make tremendous differences in the future composition and value of forest stands in the central Appalachians. Diameter growth of the crop trees was already responding to release in the first 2 yr after treatment, and the basal area composition of the stands was significantly altered. Projected stand values in the injection treatments increased dramatically because of the large differences in stumpage values between black cherry (\$800/mbf) and beech (\$30/mbf). An average of 8.77% rate of return was projected for the injection release treatments. Future research may indicate that the concentrations of herbicides used in these treatments can be lowered, further increasing the rates of return.

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