# Effect of Crown Growing Space on the Development of Young Hardwood Crop Trees

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**ABSTRACT:** *Crown release of individual crop trees can be used to increase the growth and competitiveness of selected trees in young hardwood stands. Forest managers need information on the response of individual trees to such thinnings to prescribe stand treatments that meet specific management objectives. Codominant northern red oak* (Quercus rubra *L.), chestnut oak* (Quercus prinus *L.), black cherry (*Prunus serotina *Ehrh.), and yellow-poplar* (Liriodendron tulipifera *L.) crop trees in stands 12 to 16 yr old were given a crown-touching release by cutting all adjacent trees that touched the crown of a selected crop tree. A heavier thinning, which entailed cutting all competing trees whose crowns were within 5 ft of the crown of a selected crop tree, was also applied to black cherry and yellow-poplar crop trees on one study site. Stand and individual-tree response was monitored for control and treated plots for 10 yr. Both release treatments increased periodic stand basal area growth and had a negligible effect on the proportion of high-value species among overstory trees. Individual-tree development was affected by total growing space, defined as the initial area occupied by the crop-tree crown plus the area of free growing space resulting from release. As total growing space increased, there was a positive effect on dbh, crown ratio, and crown diameter growth, and a negative effect on clear stem development. Total height growth was reduced by heavy release but not by the more moderate crown-touching release. North. J. Appl. For. 17(1):25–35.*

Crop-tree release in young hardwood stands is a precommercial thinning method that promotes the development of selected individual trees. This method entails cutting (or otherwise killing) trees that touch or are within a certain distance of the crown of a selected crop tree so that competition for light and other site resources around the crop tree is reduced. Once freed from crowding, the crop tree responds by extending its roots and branches to capture growing space formerly occupied by neighboring trees (Oliver and Larson 1996). In most cases, the crop tree also grows faster after a release treatment because the availability of site resources is less limiting once competing trees are eliminated.

Although crop-tree release usually has an obvious short-term effect on individual-tree growth, the justification for applying this practice is based on more subtle long-term effects on overall stand development and species composition. Hardwood stands in the Appalachians typically have about 50 dominant or codominant sawlog-size trees per acre at maturity that account for the majority of merchantable volume and stand value (Smith and Lamson 1986). Early crop-tree release provides an opportunity to influence the composition, quality, and rate of development of the future overstory by favoring trees in the young stand that best meet management objectives. Faster growth of selected crop trees reduces the time required to grow products of a certain size and therefore shortens the rotation length. Released crop trees also become more vigorous and competitive as they occupy more growing space. This effect has the potential to maintain or increase the proportion of desired species in the overstory as the stand matures. Increased tree vigor also is associated with higher average tree quality (Trimble and Mendel 1969). In summary, the total benefit of precommercial crop-tree release is reflected in the composition and quality of overstory trees in the mature stand.

In most studies, crop-tree release has resulted in faster dbh growth. Conflicting results have been observed in stands younger than 10 yr (Beck 1977, Trimble 1973, 1974, Hilt and Dale 1982, Smith 1977, 1979). In stands older than 10 yr, thinning treatments usually increase dbh growth of individual crop trees, particularly those that receive a complete crown release (Smith and Lamson 1983, Ward 1995, Della-Bianca 1975). However, the percentage increase in dbh growth due to crown release is inversely related to initial crown class (Smith 1977, Ward 1995). Released trees of all crown classes grew faster compared to controls, but dominant trees usually exhibited less response (as a percent of initial growth) than released trees in subordinate crown classes.

Crown release usually has no effect (Hilt and Dale 1982, Trimble 1973, 1974, Smith and Lamson 1983) or a short-term negative effect (Allen and Marquis 1970, Lamson and Smith 1989) on total height growth compared to unreleased trees. However, released trees tend to maintain their initial crown

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class better than unreleased trees (Marquis 1969, Trimble 1973, 1974). Heavy thinning reduces natural pruning of lower branches and results in less clear stem length (Lamson and Smith 1989, Sonderman 1985, 1986), though this effect may be temporary because canopy closure usually occurs within 10 yr after treatment (Drinkwater 1960). Once canopy closure is complete, the growth and development of previously released crop trees is similar to that of unreleased trees of the same size (Conover and Ralston 1959).

Previous research indicated that successful crop-tree release treatments in young hardwood stands have the following characteristics in common: (1) treatments must be delayed until canopy closure is nearly complete; (2) the crowns of preferred crop trees must be left free to grow after release; and (3) crop trees should be dominant or codominant, particularly for shade-intolerant species. These guidelines were recommended to assure that crop trees reach maturity, thus minimizing the risk and maximizing the long-term benefit associated with precommercial thinning (Smith and Lamson 1986, Lamson and Smith 1987, Heitzman and Nyland 1991). For valuable species that are intermediate in shade tolerance, such as the oaks, crop trees in subordinate crown classes might be sustained by a series of crown releases until they become established in the main canopy (Ward 1995).

The number of crop trees per acre to release depends on initial stand conditions. The first step is to define the criteria for selecting crop trees based on management objectives. Crop trees should then be selected so that desirable trees are distributed evenly throughout the stand up to a maximum number per acre. For example, in stands less than 20 yr old, the release of 50 to 75 crop trees per acre usually is sufficient to influence future stand characteristics and development (Smith and Lamson 1986).

Forest managers need information on the effect of crop-tree release treatments on dbh and height growth, crown dynamics, and stem quality of individual trees to plan effective stand treatments that meet specific objectives. Previous studies have compared the growth of released trees to that of control trees, but few have measured the impact of varying degrees of release (Drinkwater 1960). The results of this study quantify the response of individual crop trees to various amounts of total growing space for northern red oak (*Quercus rubra* L.), chestnut oak (*Quercus prinus* L.), black cherry (*Prunus serotina* Ehrh.), and yellow-poplar (*Liriodendron tulipifera* L.). Average stand response also is reported to illustrate the potential effect of crop-tree release treatments on periodic basal area growth and species composition of trees in the overstory.

## Study Sites

The Savage River site is located in Garrett County, Maryland, on the Savage River State Forest. The elevation is 2,600 ft, and the study area is on a convex ridgetop where slope is less than 10%. The soil series is described as a Gilpin silt loam (fine-loamy, mixed, mesic Typic Hapludalt) (USDA Soil Conserv. Serv. 1959). The study stand originated from a sawtimber sale completed in the 1969–1970 dormant season followed by a pulpwood sale which removed trees 4 in. dbh and larger in the spring of 1972. The site was occupied by a 70-yr-old stand of northern red oak, scarlet oak (*Quercus coccinea* L.), chestnut oak, white oak (*Quercus alba* L.), and red maple (*Acer rubrum* L.) before harvest. Records indicate that fires and repeated cutting for mine posts occurred before the property was purchased by the state of Maryland in 1930. Site index is 70 for northern red oak. When the study was installed prior to the 1986 growing season, the site was occupied by a 16-yr-old, even-age upland oak stand. Codominant trees in the new stand included northern red oak, black cherry, and chestnut oak.

The Clover Run site is located in Tucker County, West Virginia, on the Cheat Ranger District of the Monongahela National Forest. The elevation is 2,200 ft, and the landforms include mostly convex ridgetops and sideslopes where slope ranges from 15 to 25%. The soil series is described as a Dekalb channery silt loam (loamy-skeletal, mixed, mesic Typic Dystrochrept) (USDA Soil Conserv. Serv. 1967). Soil depth ranges from 28 to 34 in. The study stand originated from a sawtimber sale completed in the 1970–1971 dormant season; all trees 1.0 in. dbh and larger were cut. Prior to the clearcut operation, the site was occupied by 65-yr-old black cherry, yellow-poplar, and red maple. Site index is 77 for northern red oak. The study was installed in 1983 when the stand was 12 yr old. Black cherry, sweet birch (*Betula lenta* L.), and yellow-poplar were the predominant species in the new stand. Five-year growth results for this study site were reported by Lamson and Smith (1989).

## Methods

On each of the two study areas, six 0.25 ac square plots were installed. Each plot was surrounded by a similarly treated buffer strip approximately 50 ft wide. All trees 1.0 in dbh and larger within the plots were permanently tagged for long-term study. Species, dbh, crown class, and stem-condition remarks were recorded for all tagged trees before treatment, immediately after treatment, and again 5 and 10 yr later. Plot summaries were used to measure changes in stand basal area and species composition.

Crop trees were selected within each plot and buffer strip based on the following criteria:

*Species*: black cherry, yellow-poplar, northern red oak, chestnut oak

*Crown class*: dominant or codominant

*Quality*: straight stem, no major wounds, potential grade 1 butt log

*Risk*: no forks below 17 ft, no evidence of disease, no broken crown branches

At Savage River, plots were randomly assigned to one of two treatments: control or release. There were two control plots and four release plots. On treated plots, all competing trees that touched the crown of a selected crop tree were cut with chain saws. At Clover Run, plots were randomly assigned to one of three treatments: control, release, and release +5. Two plots were installed for each treatment. On release +5 plots, all competing trees whose crowns were within 5 ft of the crown of a selected crop tree were cut In some cases, two adjacent crop trees were left touching each other, and the release treatments were applied around both crop-tree crowns. No trees were cut on control plots.

While plot data were used to measure average stand response to treatments, a second phase of the study evaluated the response of individual crop trees. This phase of the study included at least 20 crop trees for each treatment and species on each study site. Sample trees were randomly selected from the plots and buffers, and additional trees were selected and treated adjacent to treatment plots to obtain the needed sample size.

Dbh, total height, length of clear stem, crown ratio, and crown diameter were recorded for crop trees in the individual-tree study before and immediately after treatment. Length of clear stem was defined as the height to the first live branch at least 1 ft long. Base of live crown, used to compute crown ratio, was defined as the height to the first live branch that was not an epicormic branch. Average crown diameter was determined by measuring the crown radius along the four cardinal directions. In addition, the distance from the edge of each crop tree crown to the crown of adjacent competing trees was measured along the four cardinal directions. All crop tree measurements were repeated 5 and 10 yr after treatment. Crown measurements and release distance were used to compute the total growing space ($ft^2$) available for each crop tree immediately after release. Initial growing space was computed as the circular cross-sectional area of each crop-tree crown based on the average crown radius. Free growing space was computed as the circular cross-sectional area adjacent to each crop tree based on the average release distance and the number of sides released. Total growing space is the sum of initial growing space and free growing space.

Stand and individual-tree response were evaluated for the first 5 yr after treatment and from 5 to 10 yr after treatment. Analysis of covariance (ANCOVA) was used to compare the growth response of released trees to controls, and the Tukey HSD test was used for multiple comparisons of means. In addition, least squares regression was used to relate tree response by species to total growing space. Chi-square analysis was used to compare the proportion of basal area in each species group before treatment and 10 yr later.

## Results

### Stand Growth

On each study site, the initial stands were well stocked, crop trees were distributed evenly, and canopy closure was complete before treatment. Although the stands differed in age and site index, initial basal area and the proportion of basal area removed to apply the release treatments were similar on the two study sites (Table 1). The sites also differed in initial average dbh and average number of trees cut per crop tree.

At Savage River, initial basal area averaged 83.1 $ft^2$/ac in 1,650 stems/ac for an average dbh of 3.0 in. An average of 60 crop trees/ac were released. Initial basal area was reduced by 42%. The release treatment entailed cutting 591 trees/ac, an average of 9.8 cut trees per crop tree. The cut trees averaged 3.4 in. dbh.

At Clover Run, initial basal area averaged 74.7 $ft^2$/ac in 2840 trees/ac for an average dbh of 2.2 in. An average of 80 crop trees/ac were released. Initial basal area was reduced by 43% and 70% for the release and release +5 treatments, respectively. The release treatment entailed cutting 1098 stem/ac, an average of 13.7 cut trees per crop tree. The release +5 treatment entailed cutting 1908 stem/ac, an average of 24 cut trees per crop tree. The cut trees in these treatments averaged 2.2 in. dbh.

The effect of the crown release treatments on stand growth was similar on the two study sites. Released plots had greater

**Table 1. Per acre stand summary for control and release plots.**

| | Number of trees | | | | Basal area | | | |
|---|---|---|---|---|---|---|---|---|
| | 1.0–2.9 | 3.0–4.9 | 5.0+ | Total | 1.0–2.9 | 3.0–4.9 | 5.0+ | Total |
| | (no./ac) | | | | ($ft^2$/ac) | | | |
| Savage River—Control | | | | | | | | |
| Initial | 1,456 | 438 | 72 | 1,966 | 28.5 | 34.8 | 13.6 | 76.9 |
| 10-yr | 456 | 268 | 310 | 1,034 | 8.7 | 23.1 | 75.7 | 107.5 |
| Savage River—Release | | | | | | | | |
| Initial | 820 | 536 | 136 | 1,492 | 17.4 | 44.7 | 24.1 | 86.2 |
| Cut | 288 | 243 | 60 | 591 | 6.3 | 20.1 | 10.4 | 36.8 |
| Residual | 532 | 293 | 76 | 901 | 11.1 | 24.6 | 13.7 | 49.4 |
| 10-yr | 468 | 120 | 286 | 874 | 8.6 | 10.4 | 83.7 | 102.7 |
| Clover Run—Control | | | | | | | | |
| Initial | 2,776 | 398 | 44 | 3,218 | 44.6 | 29.0 | 8.6 | 82.2 |
| 10-yr | 576 | 350 | 298 | 1,224 | 2.6 | 30.2 | 70.5 | 103.3 |
| Clover Run—Release | | | | | | | | |
| Initial | 2,224 | 390 | 60 | 2,674 | 36.4 | 28.8 | 10.4 | 75.6 |
| Cut | 888 | 186 | 24 | 1,098 | 14.5 | 13.8 | 4.1 | 32.4 |
| Residual | 1,336 | 204 | 36 | 1,576 | 21.9 | 15.0 | 6.3 | 43.2 |
| 10-yr | 744 | 232 | 244 | 1,220 | 11.3 | 20.5 | 65.1 | 96.9 |
| Clover Run—Release +5 | | | | | | | | |
| Initial | 2,248 | 352 | 28 | 2,628 | 35.0 | 26.4 | 5.0 | 66.4 |
| Cut | 1,664 | 224 | 20 | 1,908 | 26.8 | 16.2 | 3.7 | 46.7 |
| Residual | 584 | 128 | 8 | 1,720 | 8.2 | 10.2 | 1.3 | 19.7 |
| 10-yr | 1,256 | 128 | 152 | 1,536 | 19.3 | 10.3 | 46.9 | 76.5 |

**Table 2 Species composition of dominant and codominant trees at the Savage River study site**

| Treatment | N (no./ac) | Time | Species[a] CO | RO | BC | RM | Other | $X^2$ | $P$ |
|---|---|---|---|---|---|---|---|---|---|
| | | | (% of basal area) | | | | | | |
| All dominants and codominants | | | | | | | | | |
| Control | 524 | Initial | 19 | 14 | 36 | 15 | 16 | 4.977 | 0.29 |
| | 376 | 10-yr | 19 | 12 | 44 | 15 | 10 | | |
| Release | 525 | Initial | 3 | 2 | 83 | 4 | 8 | 2.847 | 0.58 |
| | 284 | 10-yr | 3 | 4 | 83 | 3 | 7 | | |
| Largest 100[b] trees/ac | | | | | | | | | |
| Control | 100 | Initial | 12 | 6 | 64 | 6 | 12 | 3.996 | 0.41 |
| | 100 | 10-yr | 10 | 8 | 74 | 0 | 8 | | |
| Release | 100 | Initial | 0 | 0 | 95 | 2 | 3 | 4.047 | 0.25 |
| | 100 | 10-yr | 1 | 0 | 98 | 0 | 1 | | |

net basal area growth than control plots over the 10 yr period ($P < 0.01$) (Table 1). Basal area of control plots increased by an average of 31 and 21 ft$^2$/ac for Savage River and Clover Run, respectively. On released plots, basal area increased by more than 53 ft$^2$/ac on both study sites. On release +5 plots, basal area growth was 57 ft$^2$/ac.

## Changes in Species Composition

Black cherry was the predominant overstory species on both study sites before treatment (Tables 2 and 3). At Savage River, basal area in dominant and codominant stems included black cherry (67%), red maple (8%), northern red oak (6%), chestnut oak (8%), and other species (11%). At Clover Run, basal area in dominant and codominant stems included black cherry (82%), sweet birch (5%), yellow-poplar (5%), northern red oak (2%), and other species (6%).

The release treatment did not significantly affect the species composition of overstory trees (all dominants and codominants) on either study site (Tables 2 and 3). At Clover Run, the release treatment slightly reduced the proportion of black cherry among overstory trees (from 89 to 83%) although differences were not significant ($P = 0.38$). However, the release +5 treatment at Clover Run significantly reduced the proportion of black cherry and increased the proportion of northern red oak and sweet birch in the overstory ($P < 0.01$). Although sweet birch was not a selected crop tree, the release +5 treatment provided additional growing space for some residual trees such that the proportion of birch in the overstory increased.

The composition of the largest 100 trees/ac, those most likely to survive to maturity, also did not exhibit a significant change due to the release treatment. At Clover Run, the release +5 treatment led to a significant increase in the proportion of northern red oak, yellow-poplar, and sweet birch, while the proportion of black cherry declined from 82 to 64% (Table 3).

## Total Height Growth

At Savage River, the release treatment had no significant effect on 10 yr height growth of the oaks or black cherry (Table 4). However, northern red oak released trees grew slightly faster than controls during the second 5 yr period after release ($P = 0.07$). Initial height of codominant black cherry averaged 37.2 ft compared to 29.8 ft for the codominant oaks, though subsequent height growth of black cherry was less than the oaks for both controls and released trees (Figure 1). Average annual height growth on this site ranged from 1.1 to 1.4 ft/yr, depending on species (Table 4).

At Clover Run, results varied by species and treatment For black cherry, the release treatment did not affect height

**Table 3. Species composition of dominant and codominant trees at the Clover Run site.**

| Treatment | N (no./ac) | Time | Species[a] SB | RO | YP | BC | Other | $X^2$ | $P$ |
|---|---|---|---|---|---|---|---|---|---|
| | | | (% of basal area) | | | | | | |
| All dominants and codominants | | | | | | | | | |
| Control | 444 | Initial | 7 | 2 | 4 | 83 | 4 | 3.310 | 0.51 |
| | 392 | 10-yr | 5 | 3 | 3 | 87 | 2 | | |
| Release | 396 | Initial | 4 | 1 | 2 | 89 | 4 | 4.209 | 0.38 |
| | 332 | 10-yr | 8 | 1 | 2 | 83 | 6 | | |
| Release+5 | 378 | Initial | 6 | 4 | 8 | 72 | 10 | 14.006 | <0.01 |
| | 214 | 10-yr | 18 | 7 | 7 | 60 | 8 | | |
| Largest 100[b] trees/ac | | | | | | | | | |
| Control | 100 | Initial | 0 | 0 | 0 | 94 | 6 | 2.211 | 0.33 |
| | 100 | 10-yr | 0 | 0 | 4 | 92 | 4 | | |
| Release | 100 | Initial | 0 | 2 | 6 | 90 | 2 | 5.186 | 0.27 |
| | 100 | 10-yr | 6 | 0 | 6 | 82 | 6 | | |
| Release+5 | 100 | Initial | 2 | 4 | 8 | 82 | 4 | 14.461 | <0.01 |
| | 100 | 10-yr | 4 | 12 | 14 | 64 | 6 | | |

[a] Chestnut oak (CO), red oak (RO), black cherry (BC), red maple(RM), sweet birch (SB), yellow-poplar (YP).
[b] Largest 100 dominants and codominants based on initial dbh and dbh 10 yr later.

**Table 4 Average height growth for released and control trees**

| Area* | Species | Treatment | Sample size (no.) | Average annual growth 0–5 yr | 5–10 yr | 0–10 yr |
|---|---|---|---|---|---|---|
| | | | | (ft/yr) | | |
| Savage River | Northern red oak | Control | 21 | 1.17 | 1.53 | 1.35 |
| | | Release | 23 | 1.09 | 1.80 | 1.44 |
| | | | | (0.48)† | (0.07) | (0.13) |
| | Chestnut oak | Control | 20 | 1.34 | 1.30 | 1.33 |
| | | Release | 22 | 1.31 | 1.30 | 1.30 |
| | | | | (0.77) | (0.89) | (0.77) |
| | Black cherry | Control | 21 | 0.80 | 1.34 | 1.07 |
| | | Release | 21 | 1.19 | 0.98 | 1.08 |
| | | | | (0.39) | (0.46) | (0.85) |
| Clover Run | Black cherry | Control | 30 | 2.17a†† | 1.61a | 1.89a |
| | | Release | 37 | 1.70ab | 1.81a | 1.76ab |
| | | Release+5 | 37 | 1.47b | 1.63a | 1.55b |
| | | | | (<0.01) | (0.28) | (<0.01) |
| | Yellow-poplar | Control | 30 | 2.76a | 0.76a | 1.76a |
| | | Release | 29 | 2.77a | 1.22b | 2.00b |
| | | Release+5 | 33 | 2.07b | 1.09a | 1.58a |
| | | | | (<0.01) | (<0.01) | (<0.01) |

* Savage River initial age = 16, Clover Run initial age = 12.
† $Pr > F$ from analysis of covariance in parentheses.
†† For each species, values in columns followed by the same letter are not significantly different ($P > 0.01$) using Tukey-Kramer HSD.

growth compared to controls, while the release +5 treatment significantly reduced height growth. Slower height growth was observed for the release +5 treatment during the first 5 yr when free growing space was at a maximum, but not during second 5 yr when free growing space was decreasing (Table 4) For yellow-poplar, the release treatment resulted in significantly faster height growth compared to the controls and the release +5 treatment (Table 4). Height growth for the release treatment was similar to controls for the first 5 yr, then faster during the second 5 yr. Initial height was similar for codominant black cherry and yellow-poplar on this site, averaging 34.7 ft (Figure 1). Average annual height growth averaged 1.6 to 2.0 ft, with the least height growth observed for the release +5 treatment (Table 4).

## Dbh Growth

Each species exhibited a significant increase in dbh growth due to the release treatments (Figure 2). Released trees grew faster than controls during both the first and second 5 yr periods after release ($P < 0.01$) (Table 5). For northern red oak and chestnut oak, average dbh growth was greater during the second 5 yr period. For black cherry and yellow-poplar, average dbh growth was greater during the first 5 yr period. These growth trends for the two 5 yr periods were observed for both control and released trees. For black cherry, dbh growth response was the same on both study sites for the release treatment ($P = 0.84$). Data are summarized separately by study site to illustrate how growth compared to other species on the same site (Table 5).

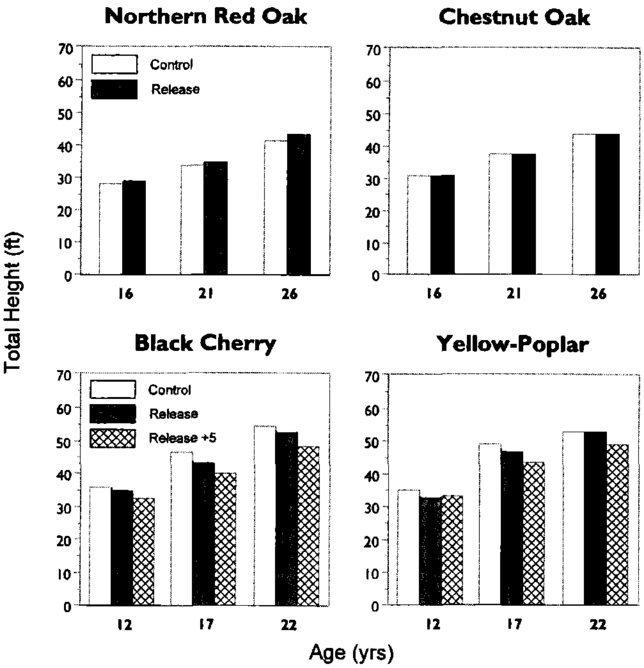


**Figure 1. Total height of released and control trees over 10 yr.**

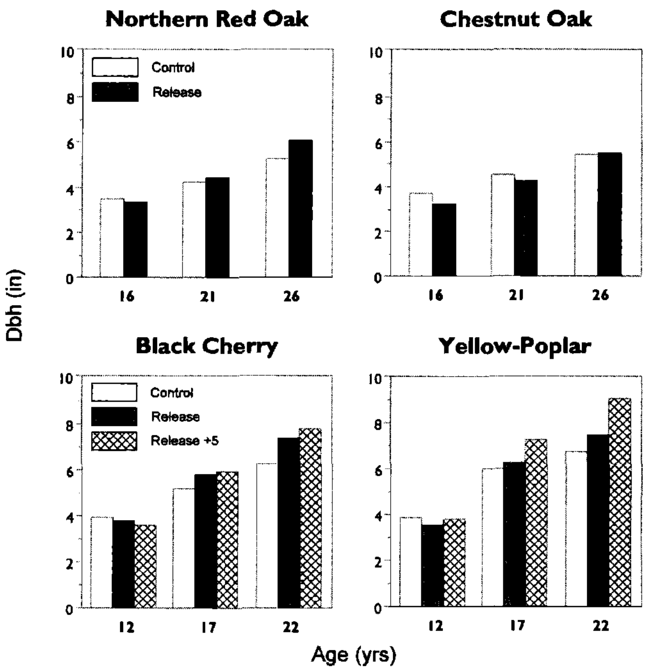


**Figure 2. Dbh of released and control trees over 10 yr.**

**Table 5 Average dbh growth for released and control trees**

| Area* | Species | Treatment | Sample size (no.) | Average annual growth 0–5 yr | 5–10 yr | 0–10 yr |
|---|---|---|---|---|---|---|
| | | | | (in./yr) | | |
| Savage River | Northern red oak | Control | 21 | 0.15 | 0.20 | 0.18 |
| | | Release | 23 | 0.23 | 0.32 | 0.28 |
| | | | | (<0.01)† | (<0.01) | (<0.01) |
| | Chestnut oak | Control | 20 | 0.16 | 0.19 | 0.17 |
| | | Release | 22 | 0.21 | 0.24 | 0.23 |
| | | | | (<0.01) | (<0.01) | (<0.01) |
| | Black cherry | Control | 21 | 0.24 | 0.20 | 0.22 |
| | | Release | 21 | 0.45 | 0.32 | 0.39 |
| | | | | (<0.01) | (<0.01) | (<0.01) |
| Clover Run | Black cherry | Control | 30 | 0.25a†† | 0.22a | 0.24a |
| | | Release | 37 | 0.40b | 0.32b | 0.36b |
| | | Release+5 | 37 | 0.47c | 0.36b | 0.42c |
| | | | | (<0.01) | (<0.01) | (<0.01) |
| | Yellow-poplar | Control | 30 | 0.42a | 0.16a | 0.29a |
| | | Release | 29 | 0.55b | 0.25b | 0.40b |
| | | Release+5 | 33 | 0.70c | 0.36c | 0.53c |
| | | | | (<0.01) | (<0.01) | (<0.01) |

* Savage River initial age = 16, Clover Run initial age = 12.
† Pr > F from analysis of covariance in parentheses.
†† For each species, values in columns followed by the same letter are not significantly different (P > 0.01) using Tukey-Kramer HSD.

The average annual dbh growth for released trees ranged from 0.23 in. for chestnut oak to 0.40 in. for yellow-poplar. The release treatment increased dbh growth by 35–77% compared to controls. After 10 yr, dbh growth of released trees exceeded that of controls by an average of 0.6, 1.0, 1.1, and 1.4 in. for chestnut oak, northern red oak, yellow-poplar, and black cherry, respectively. This trend is expected to continue for a few more years until crown expansion eliminates any remaining free growing space (Oliver and Larson 1996). The release +5 treatment increased dbh growth by 75–82% compared to controls.

## Crown Development

Released trees had greater crown diameter growth than controls after 10 yr (Table 6). Most of the faster growth occurred during the first 5 yr. During the second 5 yr period, crown diameter growth diminished for both released and control trees. For black cherry and yellow-poplar, crown diameter growth was negative during the second 5 yr (Figure 3). The reduction in crown diameter for shade-intolerant species was the result of dieback of long branches that developed after release. Released trees rapidly expanded their crowns when free growing space was available. After 5 yr, crown expansion had reduced the free growing space around individual crop trees, and the reduction in crown diameter for released trees was similar to controls. Crown diameter reduction will probably continue for a few years as the canopy closes, although released trees will have larger crowns than the controls once the canopy is closed. For yellow-poplar and black cherry, the average annual crown diameter growth was 0.52 ft for released trees, 0.86 ft for release +5 trees,

**Table 6. Average crown diameter growth for released and control trees.**

| Area* | Species | Treatment | Sample size (no.) | Average annual growth 0–5 yr | 5–10 yr | 0–10 yr |
|---|---|---|---|---|---|---|
| | | | | (ft/yr) | | |
| Savage River | Northern red oak | Control | 21 | 0.37 | –0.03 | 0.17 |
| | | Release | 23 | 0.92 | 0.13 | 0.53 |
| | | | | (<0.01)† | (0.31) | (<0.01) |
| | Chestnut oak | Control | 20 | 0.29 | 0.05 | 0.17 |
| | | Release | 22 | 0.77 | 0.03 | 0.40 |
| | | | | (<0.01) | (0.83) | (<0.01) |
| | Black cherry | Control | 21 | 0.45 | –0.39 | 0.03 |
| | | Release | 21 | 1.43 | –0.25 | 0.59 |
| | | | | (<0.01) | (0.26) | (<0.01) |
| Clover Run | Black cherry | Control | 30 | 0.43a†† | –0.32a | 0.05a |
| | | Release | 37 | 1.73b | –0.68b | 0.52b |
| | | Release+5 | 37 | 1.82b | –0.11a | 0.86c |
| | | | | (<0.01) | (<0.01) | (<0.01) |
| | Yellow-poplar | Control | 30 | 0.76a | –0.90a | –0.07a |
| | | Release | 29 | 1.79b | –0.83a | 0.48b |
| | | Release+5 | 33 | 2.27c | –0.53b | 0.87c |
| | | | | (<0.01) | (<0.01) | (<0.01) |

* Savage River initial age = 16, Clover Run initial age = 12.
† Pr > F from analysis of covariance in parentheses.
†† For each species, values in columns followed by the same letter are not significantly different (P > 0.01) using Tukey-Kramer HSD.

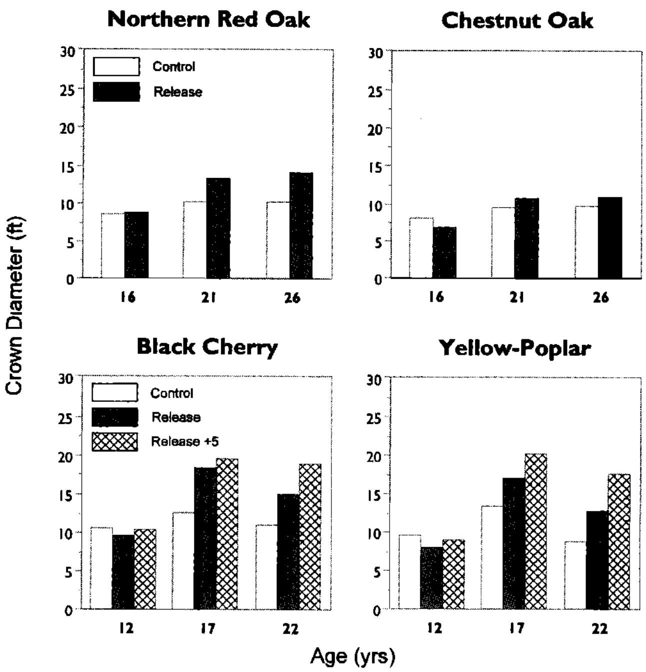


**Figure 3. Crown diameter of released and control trees over 10 yr.**

and less than 0.1 ft for controls. For the oaks, crown diameter growth averaged 0.47 and 0.17 ft/yr for released trees and controls, respectively.

Initial crown ratio of selected crop trees averaged 52% at Savage River and 43% at Clover Run. For black cherry and yellow-poplar, released trees had a significant increase in crown ratio over 10 yr, with most of the increase in the first 5 yr after treatment. Crown ratio decreased for control trees. At Savage River, crown ratio of black cherry increased 2% for released trees and decreased 10% for controls. At Clover Run, crown ratio of black cherry increased by 6% for released trees, 12% for release +5 trees, and no change for the control trees. For yellow-poplar, crown ratio increased by 8%, 14%, and 7% in the release, release +5, and controls, respectively. There was no significant difference in crown ratio for the oaks; both released and control trees declined from 52 to 47 % over the 10 yr period.

### Clear Stem Development

For all species, clear stem development was greater for control than for released trees during the first 5 yr period ($P < 0.01$) (Table 7). The additional crown growing space for released trees tended to reduce natural pruning. Although clear stem length continued to increase for released trees, the rate of increase was less than that for controls. However, during the second 5 yr, the reverse generally was true—released trees had greater increases in clear stem length than controls.

For northern red oak and chestnut oak, the release treatment did not have a significant effect on clear stem development over the 10 yr study period (Table 7). Initial clear stem length for the oaks averaged 12.6 ft, and it increased by an average of 7 ft for both released and control trees. For black cherry and yellow-poplar, clear stem length increased more for control trees than released trees over the same period. For these species at Clover Run, initial clear stem averaged 17 ft. After 10 yr, clear stem length averaged 30 ft on control trees, 26 ft on released trees, and 20 ft on release +5 trees (Figure 4).

### Changes in Degree of Release

After treatment, crop trees were free to grow on all sides of their crowns, except where two crop trees were left touching each other. The average release distance between adjacent tree crowns was 5.0 for the release treatment and 9.8 ft for the release +5 treatment. During the first 5 yr after release, crown expansion reduced both the number of sides free to grow and the release distance between adjacent crowns. Released trees had two sides free to grow for an average distance of 2.8 ft after 5 yr. Release +5 trees had three sides free to grow for an average distance of 6.5 ft after 5 yr. After 10 yr, released trees had an average of one side free to

**Table 7. Average change in clear stem length for released and control trees.**

| Area* | Species | Treatment | Sample size (no.) | Average annual growth 0–5 yr | 5–10 yr | 0–10 yr |
|---|---|---|---|---|---|---|
| | | | | (ft/yr) | | |
| Savage River | Northern red oak | Control | 21 | 0.92 | 0.55 | 0.74 |
| | | Release | 23 | 0.40 | 1.10 | 0.75 |
| | | | | (<0.01)† | (0.06) | (0.63) |
| | Chestnut oak | Control | 20 | 0.92 | 0.66 | 0.79 |
| | | Release | 22 | 0.06 | 1.02 | 0.54 |
| | | | | (<0.01) | (0.20) | (0.57) |
| | Black cherry | Control | 21 | 0.57 | 0.99 | 0.78 |
| | | Release | 21 | –0.46 | 0.99 | 0.26 |
| | | | | (<0.01) | (0.99) | (<0.01) |
| Clover Run | Black cherry | Control | 30 | 1.45a†† | 1.15a | 1.30a |
| | | Release | 37 | 0.51b | 1.60b | 1.05b |
| | | Release+5 | 37 | 0.29b | 0.61c | 0.45c |
| | | | | (<0.01) | (<0.01) | (<0.01) |
| | Yellow-poplar | Control | 30 | 1.64a | 0.95a | 1.29a |
| | | Release | 29 | 0.57b | 1.17a | 0.87b |
| | | Release+5 | 33 | –0.14c | 0.75a | 0.30c |
| | | | | (<0.01) | (0.31) | (<0.01) |

* Savage River initial age = 16, Clover Run initial age = 12.
† Pr > F from analysis of covariance in parentheses.
†† For each species, values in columns followed by the same letter are not significantly different ($P > 0.01$) using Tukey-Kramer HSD.

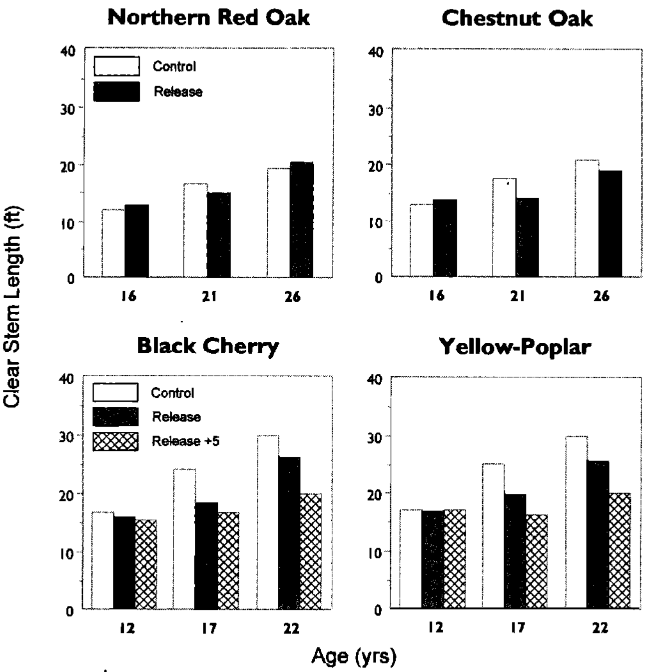


**Figure 4. Clear stem length of released and control trees over 10 yr.**

grow for an average distance of 2 ft, and release +5 trees had an average of two sides free to grow for an average of 3 ft.

### Changes in Crown Class and Survival

At Savage River, an average of 15% of control trees (three trees in each species) dropped from codominant to intermediate crown class in 10 yr. For released trees, only one chestnut oak dropped to intermediate class, while all northern red oak and black cherry maintained a codominant position. At Clover Run, no black cherry and five yellow-poplar controls (17%) dropped from codominant to intermediate class. All released black cherry and yellow-poplar crop trees on this site maintained a codominant position throughout the study.

Crown release did not affect survival of codominant crop trees for any species. None of the black cherry or chestnut oak crop trees died during the 10 yr study. One released yellow-poplar crop tree and two controls died during the second 5 yr period. One northern red oak control tree died during the first 5 yr period.

### Regression Analyses

The discrete analysis used to compare the growth of released crop trees to controls did not indicate how various amounts of growing space affect tree response. Regression analyses revealed that increased growing space had a positive effect on dbh and crown diameter growth and a negative effect on clear stem development (Tables 8–10) Height growth was not related to the amount of growing space resulting from crown release treatments in this study.

Other studies of crown release indicated that dbh growth increases with the number of sides or crown perimeter left free to grow after treatment (Lamson et al.1990, Perkey et al.1994). In this study, the majority of released crop trees were free to grow on four sides after treatment, while the distance between the crowns of competing trees varied greatly Results of the regression analyses indicated that the distance between the crowns of competing trees also affects the magnitude of the growth response. Crop trees with a greater degree of release were free to grow for a longer period of time, thus they exhibited greater increases in dbh and crown diameter growth than trees with less release.

Trends apparent from the regression analyses suggest a practical trade-off exists between faster growth and reduced tree quality for the species studied. Annual dbh and crown diameter growth increased with added growing space, while too much growing space had a negative effect on clear stem development (Tables 8–10). Beyond a certain amount of growing space, reduced tree quality would offset faster growth. The release treatments applied to crop trees in this study resulted in faster growth with little difference in clear stem development during second 5 yr period after release (Table 7). These results indicate that heavier release treatments are not recommended if maintenance of tree quality is a management objective.

Black cherry exhibited similar growth responses at Savage River and Clover Run, and the resulting regression equations were not significantly different for dbh growth ($P = 0.53$) or crown diameter growth ($P = 0.83$). There was a significant difference in clear stem development ($P < 0.01$) Clear stem growth was greater at Clover Run, where site index is greater, and the development of epicormic branches is less likely.

## Discussion

For the four species observed in this study, the crown release treatments significantly enhanced dbh and crown growth with no adverse effect on survival or crown position for 10 yr after treatment. However, when black cherry and yellow-poplar crop trees were given a release +5 treatment, the results indicated that too much growing space can be detrimental to height growth. For both species, height growth was significantly reduced during the first 5 yr after the release +5 treatment. Total height of black cherry crop trees increased by an average of 18.9 ft,

**Table 8. Regression parameters from equations relating dbh growth response to amount of total growing space.**

| Species | $N$ | Regression coefficient $b_0$ | Regression coefficient $b_1$ | $S_{y.x}$ | $R^2$ |
|---|---|---|---|---|---|
| Northern red oak | 44 | 0.170514 | 0.000324 | 0.053 | 0.46 |
| Chestnut oak | 42 | 0.154580 | 0.000270 | 0.043 | 0.43 |
| Black cherry | 146 | 0.244859 | 0.000260 | 0.092 | 0.36 |
| Yellow-poplar | 92 | 0.291649 | 0.000352 | 0.083 | 0.60 |

MODEL: $y = b_0 + b_1 GS + e$, where $y$ = annual dbh growth in inches, $b$ = estimated regression coefficients, $GS$ = growing space in square feet. $P < 0.01$ for $F$ test of model fit for each species and for $t$-test of each coefficient.

**Table 9 Regression parameters from equations relating crown diameter growth to amount of total growing space**

| Species | N | Regression coefficient $b_0$ | $b_1$ | $S_{y,x}$ | $R^2$ |
|---|---|---|---|---|---|
| Northern red oak | 44 | 0.141053 | 0.001129 | 0.224 | 0.37 |
| Chestnut oak | 42 | 0.143990 | 0.000865 | 0.211 | 0.24 |
| Black cherry | 146 | 0.102067 | 0.001041 | 0.298 | 0.47 |
| Yellow-poplar | 92 | 0.023688 | 0.001246 | 0.273 | 0.63 |

Model: $y = b_0 + b_1 GS + e$, where $y$ = annual crown diameter growth in feet, $b$ = estimated regression coefficients, $GS$ = growing space in square feet. $P < 0.01$ for $F$ test of model fit for each species and for $t$-test of each coefficient.

17 6 ft, and 15.5 ft for the control, release, and release +5 treatments, respectively, after 10 yr (Figure 1). As a result, the heavily released crop trees could be significantly shorter than adjacent trees as the canopy closes 10 to 15 yr after treatment. Such a reduction in height growth could result in crown class regression and threaten the long-term chances of survival, particularly for shade-intolerant species like black cherry. Previous studies have also shown that heavy thinning can have a negative effect and light thinning can have a positive effect on height growth (Allen and Marquis 1970, Trimble 1973). Forest managers should avoid prescribing the release +5 treatment to minimize the risk of reduced height growth and possible crown class regression among desirable crop trees.

Lamson and Smith (1989) concluded that providing crop trees with more than a crown-touching release could adversely affect stem quality for young hardwoods. A moderate increase in crown growing space, as provided in the release treatment, reduced clear stem development by an average of 4 ft for black cherry and yellow-poplar (Table 7). This is probably an acceptable trade-off for increased dbh and crown growth 10 yr after treatment in such young stands. The canopy was nearly closed at the end of the 10 yr period, and this small reduction in clear stem may be negligible in the future as small branches die under the shade of the canopy. However, clear stem development was reduced by an average of 10 ft after the release +5 treatment, and the canopy was still open 10 yr after treatment. These conditions pose a more serious threat to potential stem quality because branches can persist and grow for many more years after the release +5 treatment. These results also suggest that a simple crown-touching release is an effective, low-risk cultural treatment for young hardwood stands.

Dbh growth was increased from 35 to 77% due to release, and the average dbh of released trees was 1.1 in. greater than controls after 10 yr (Figure 5). Released trees received a complete crown release, and most trees still were free to grow on 1 or 2 sides 10 yr after treatment. Enhanced dbh growth is expected to continue until crown expansion eliminates the remaining free growing space available to the crop trees. These trends indicate that faster dbh growth can be expected for 12 to 15 yr after treatment, and dbh of released trees can be expected to be about 1.5 in. larger than controls once the canopy is fully closed. As a result, the released crop trees will grow to a given dbh about 7 to 10 yr sooner than the unreleased crop trees in the future. Forest managers can use this information to evaluate the economic benefit of release treatments in terms of a reduction in rotation length or time required to grow products to a desired minimum dbh.

Crown release treatments did not significantly alter the species composition of overstory trees in this study because the initial stand composition was already dominated by desirable species. For example, black cherry, northern red oak, chestnut oak, and yellow-poplar, accounted for the vast majority of basal area in each of the study plots before treatment, thus leaving little opportunity for improving species composition. Although the release treatments did not alter species composition during the study, virtually all released crop trees had maintained their codominant canopy position and their potential to survive to maturity, while some codominant oaks and yellow-poplar control trees regressed to an intermediate crown position. After regressing to an intermediate crown class, these trees have little chance to survive to maturity (Trimble 1974). The results demonstrated that crown release is a reliable method for enhancing the growth of individual codominant trees and sustaining their competitiveness in the canopy. In mixed stands, where preferred crop trees are competing with less desirable species, crown release can be used to enhance the long-term competitiveness of the crop trees. As the stand matures and the number of overstory trees declines to about 50/ac (Smith and Lamson 1986), the released crop trees will comprise the majority of the dominant species.

**Table 10. Regression parameters from equations relating clear stem growth to amount of total growing space.**

| Species | N | Regression coefficient $b_0$ | $b_1$ | $S_{y,x}$ | $R^2$ |
|---|---|---|---|---|---|
| Northern red oak | 44 | 0.915998 | −0.001406 | 0.499 | 0.16 |
| Chestnut oak | 42 | 0.924394 | −0.002750 | 0.944 | 0.14 |
| Black cherry | 42[a] | 0.556568 | −0.002490 | 0.956 | 0.12 |
| | 104[b] | 1.218849 | −0.001333 | 0.728 | 0.22 |
| Yellow-poplar | 92 | 1.148000 | −0.002445 | 0.728 | 0.48 |

[a] Savage River site.
[b] Clover Run site.
Model: $y = b_0 + b_1 GS + e$, where y = annual clear stem growth in feet, $b$ = estimated regression coefficients, $GS$ = growing space in square feet. $P < 0.01$ for $F$ test of model fit for each species and for $t$-test of each coefficient.

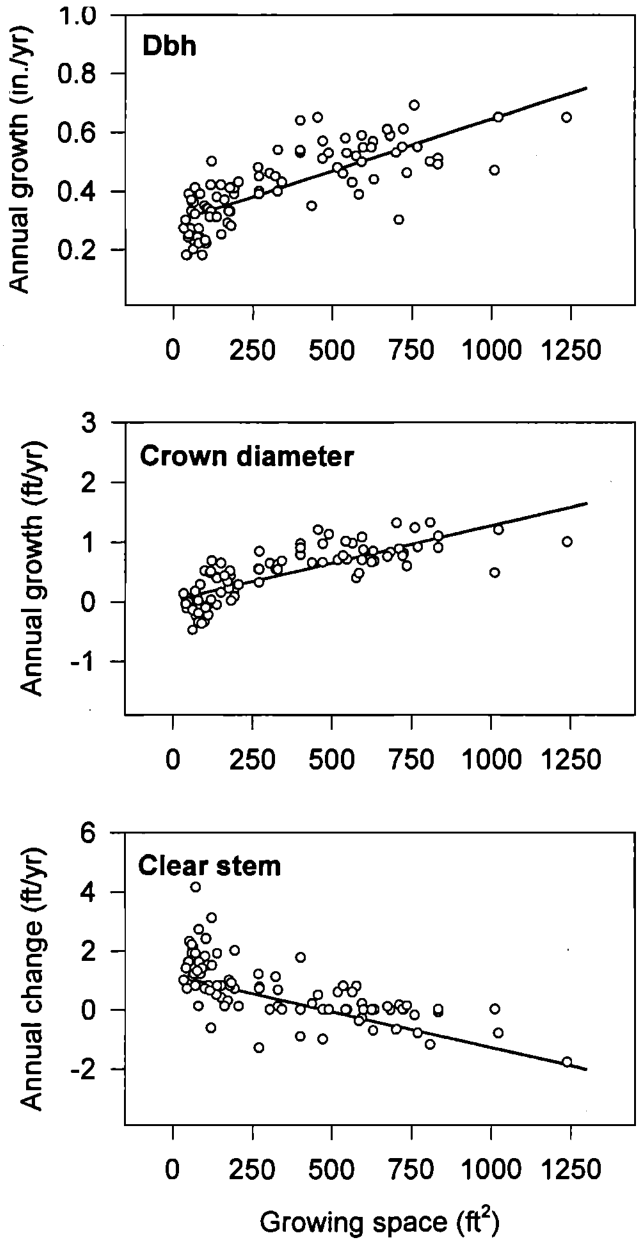


**Figure 5. Estimated regressions and data points for annual dbh growth, crown diameter growth, and change in clear stem length as functions of total growing space for yellow-poplar.**

This study was conducted in young even-aged stands, although similar precommercial crown release treatments also can be applied in uneven-aged stands managed by group selection. After group selection harvests, new reproduction occurs in small patches where trees of the same age develop in close proximity, and competition among trees is similar to that observed in young even-aged stands (Miller et al. 1995). Crown release treatments can be applied to crop trees in small patches of reproduction using the same guidelines as those recommended for even-aged stands.

Forest managers may question the feasibility of crown release treatments if individual trees are in a weak codominant or intermediate crown position before treatment. For shade-intolerant species, particularly yellow-poplar and black cherry, crop trees in a subordinate crown class usually do not respond to crown release (Trimble 1973, Trimble 1974, Smith and Lamson 1983) However, crown release may provide an opportunity to sustain species like northern red oak that are intermediate in shade tolerance. At Savage River, 25 northern red oaks in an intermediate crown class were selected to measure the effect of crown release on trees in a subordinate canopy position. The average total height for these trees was 26.9 ft, about 2 ft less than neighboring codominant trees. This group included 13 released trees and 12 controls. Among the released trees, all trees survived (100%) and four trees (31%) grew into a codominant crown position after 10 yr. Among the controls, only five trees survived (41%), and two trees (17%) were codominant after 10 yr. In addition, height growth of codominant trees was significantly increased in the second 5 yr after release (Table 4), indicating that oaks may exhibit a delayed increase in height growth in response to increased competition as the canopy closes. Further research is needed to determine the proportion of intermediate oaks that grow to a codominant crown position after a crown release treatment (Ward 1995)

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