

Technical Guide to Crop Tree Release in Hardwood Forests

Gary W. Miller, Research Silviculturist, Forest Service, U.S. Department of Agriculture, Northern Research Station
Jeffrey W. Stringer, Extension Professor of Hardwood Silviculture, Department of Forestry, University of Kentucky
David C. Mercker, Extension Specialist, Department of Forestry, Wildlife and Fisheries, University of Tennessee

Crop tree release (CTR) is a widely applicable silvicultural technique used to enhance the performance of individual trees. It offers flexibility in that it can be applied on small or large properties, and with certain modifications, it can be applied as a precommercial or commercial operation. By favoring the development of selected crop trees within a hardwood stand, the landowner can meet a variety of area-wide management objectives such as wildlife habitat, recreation, timber value, aesthetic beauty and species diversity. CTR can be applied at various stages of development, including sapling, pole and sawtimber stands, depending on the specific opportunities to improve stand conditions. In some cases, it may be advisable to apply CTR more than once during the rotation. As forest managers gain experience with CTR, many come to realize that it is a versatile silvicultural technique that can be effective in many situations (Houston et al. 1995; Perkey et al. 1994; Perkey and Wilkins 2001; Singer and Lorimer 1997).

CTR is not consistently defined in forestry literature and is often assumed to be synonymous with thinning, improvement cutting or timber stand improvement. CTR is an intermediate silvicultural treatment intended to provide increased growing space to selected trees through the removal of crown competition from adjacent trees (Figure 1). Although CTR could be considered a special type of thinning, traditional thinning techniques



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Figure 1. The competing trees adjacent to this crop tree have been removed, thus leaving free growing space around its crown.



are intended to reach a desired area-wide residual stand density or remove specific sizes or crown classes of trees. CTR differs from traditional thinning in that it assures that most site resources are focused on a small number of selected trees rather than being widely distributed to all residual trees. CTR can be applied in both even-aged and uneven-aged stands; it is applicable in any situation where the forest manager intends to reallocate site resources to selected crop trees. While the term “crop tree” suggests a tree that has been selected for future harvest, CTR can be applied to trees that will be either harvested or retained for any number of years, depending on how they provide desired benefits or meet management objectives.

Although CTR is relatively simple to apply, two key concepts are important to consider for optimal use of the technique. These concepts are understanding how crop trees help meet management objectives and how reducing competition for site resources around crop trees enhances their vigor and development. This publication provides forest managers and landowners with guidelines for applying CTR in hardwoods and technical information based on published research. Several mechanical and chemical methods for releasing crop trees are described, and useful references are provided for more in-depth coverage of specific topics.

What Is a Crop Tree?

A crop tree is one that exhibits desirable characteristics that help meet management objectives, has the ability to respond to treatment and can remain competitive for many years. Management objectives vary among landowners and often include wildlife habitat, maintenance of stand diversity, timber production and forest health. For each landowner or individual stand, the criteria used to define a crop tree can differ. However, in all cases, crop trees must possess a crown structure and canopy position that allows them to respond to release and remain competitive as the stand matures. Table 1 provides examples of crop tree criteria by common management objectives. Crop trees are found only in the dominant, codominant or strong intermediate crown classes. In limited cases, valuable mid-tolerant species in strong intermediate crown classes can be released if they are critical for meeting management objectives. In most cases, however, trees in suppressed or intermediate crown classes will not provide acceptable response to CTR. Crop trees can be selected to meet multiple objectives in

the same stand, and selection criteria can often be adjusted to accommodate unique circumstances.

Selecting Crop Trees

The purpose of CTR is to reduce competition around selected trees so that they improve in vigor, remain competitive in the stand and provide desired future benefits. The key characteristics to consider in selecting crop trees include species, crown class, origin, bole quality, vigor and risk. It is also important to select trees that are appropriately adapted to local site conditions.

Species

Species is the main factor that defines a crop tree's capacity to meet management objectives. Market value, wildlife value and more subtle benefits such as aesthetics, diversity and recreation are determined by the stand species composition. Once management objectives are defined, the candidate species for crop trees become clear. Crop trees have relatively high value in local markets. They also provide suitable seed production for future regeneration and wildlife food. Crop trees diversify the species mix in the overstory to provide a range of other benefits and reduce the risk of insect and disease attack problems associated with low species diversity. Some species can be relatively scarce or have only a few remaining representatives within a given stand. If site conditions are suitable, including such trees in the CTR prescription helps ensure species diversity.

Crown Class

Crop trees must be able to compete successfully after release in the forest community and live long enough to provide benefits that meet management objectives; thus crop trees are usually found in dominant or codominant crown classes. For shade-intolerant and mid-tolerant species, the survival rate for crop trees in the dominant or codominant crown classes usually exceeds 90 percent for decades after CTR, thus providing adequate time to recover the desired benefits (Ward and Stephens 1994). Trees in intermediate or suppressed crown classes, particularly shade-intolerant species, generally do not respond well to CTR. Height growth for subordinate trees is usually too slow to keep pace with their codominant competitors. Some trees in the intermediate crown class, such as shade-tolerant maples or beech, can be sustained by CTR, but few grow into the upper crown classes. Similarly, a few subordinate trees of mid-tolerant species, such as the oaks, can

Table 1. Crop tree characteristics for common management objectives.

Criteria	Management Objectives		
	Wildlife ¹	Timber	Diversity
Species	Suitable hard and soft mast-producing species for the desired wildlife species	Commercial species that are relatively valuable in local markets	Additional species that do not necessarily meet wildlife or timber objectives.
Crown class	Dominant, co-dominant, strong intermediate	Dominant, co-dominant, strong intermediate	Dominant, co-dominant, strong intermediate
Crown form	Live crown ratio > 30 percent	Evenly distributed around circumference, live crown ratio > 30 percent	Live crown ratio > 30 percent
Bole characteristics	Normal bark pattern indicating adequate vigor and health.	Straight, clear bark pattern, sound wood, no disease or defects.	Not important
Risk	Good health and vigor, no low forks, cankers or other visible indications that it will not live long enough to meet objectives.	Good health and vigor, no low forks, cankers or other visible indications that it will not live long enough to meet objectives.	Good health and vigor, no low forks, cankers or other visible indications that it will not live long enough to meet objectives.
Age	Any age; expected to live long enough to meet objectives.	Any age; expected to live long enough to meet objectives.	Any age; expected to live long enough to meet objectives.
Other	Bark texture suitable for bat roosting or supplying insects and shelter for birds	No evidence of epicormic branches or diseases that will reduce wood quality.	A relatively scarce species on the site. Diversity can include species, age, size and stand structural criteria, depending on specific objectives.

¹ These criteria are based on a general wildlife objective of improving diversity of habitats for a range of game and non-game species.



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Figure 2. Seedling-origin crop trees develop as single-stem trees, while sprout-origin crop trees develop in multiple-stem clumps. For sprout clumps, select the best two trees and release around them as if they are one.

be enhanced by CTR to grow into the upper crown classes, but the success rate in improving crown class is usually less than 20 percent (Miller 2000). Trees in the intermediate crown class should be selected only as a last resort, and the forest manager should expect limited long-term success for the investment.

Origin

Both seedling-origin and sprout-origin trees can be acceptable crop trees. Sprout-origin crop trees should exhibit low attachment to the parent stump, and if possible, be located on the uphill side of the stump. Sometimes sprout clumps have more than one acceptable crop tree on the same clump. In such cases, select the two best trees, preferably with a u-shape connection between them, and release around both crowns as if they are one (Figure 2).

Bole Quality, Vigor and Risk

Crop tree quality, vigor and risk are closely related. Several research trials indicated that young hardwood trees with straight, defect-free boles tend to retain these qualities as they grow (Sonderman 1987; Miller and Stringer 2004; Miller et al. 2007). In addition, early CTR in young stands has little adverse effect on bole quality (Miller 2000). Desirable crop trees have straight boles; no forks in the bottom 17-foot bole section; no evidence of disease or damage; and bark that has a healthy, normal appearance (Figure 3). Evidence of epicormic branching before release indicates that more branches are likely to form after release. Crop trees also have healthy crowns with at least 30 percent live crown ratio and no evidence of crown dieback.

Site Quality

Hardwood species have varying degrees of competitiveness, depending on site quality. Site quality can range from dry ridge sites with shallow soil to moist cove sites with deep soil. Select crop trees that are well-adapted to site conditions to minimize the risk of poor performance or even death over several decades. Draw on local experi-



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Figure 3. Avoid selecting trees with low forks on the bole, as they are susceptible to crown breakage, severe tree damage and a loss of resources invested in CTR treatments.



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Figure 4. This crop tree is fully released, and its crown will expand more rapidly than those of adjacent trees that are only partially released. After CTR, the crop tree will develop a greater crown ratio and have a competitive advantage over adjacent trees for many years.

ence and professional judgment to select crop trees that have the ability to compete well and reach the desired age on the site.

How Crop Trees Respond to Release

Trees growing in forest communities compete for sunlight, water and soil nutrients. These resources are vital for photosynthesis and growth. A tree's ability to capture site resources through its crown and root system ultimately determines its ability to compete and survive. As resources become limiting due to competition from adjacent trees, the vigor and growth of the tree can be diminished. If competition becomes too severe and site resources become too limiting, some trees will die. Their death leads to reallocation of site resources among the surviving trees. The sequence of severe competition followed by mortality and reallocation of resources to the surviving trees is an ongoing process in hardwood stands.

When trees adjacent to a crop tree are cut or killed as part of a CTR treatment, more sunlight,

water and nutrients become available to the crop tree (Figure 4). As a result, its crown and roots expand into the free growing space, thus further improving its capacity to gather site resources and compete with neighboring trees for many years. Once released, crop trees respond with faster growth in first root and crown expansion, then faster dbh and volume growth.

Although CTR can produce a significant response in the first growing season, maximum growth usually occurs several years after the release (Stringer and Wittwer 1985). Research has shown that initial dbh growth response to release can vary by species. For example, in the initial 5-year response after CTR, yellow-poplar exhibited a linear increase in dbh growth related to the degree of crown release (Figure 5). This is in contrast to two oak species where there was little added benefit of increasing the degree of release from two to four sides. These results represent only the initial 5-year response. It is important to realize that oaks, as is the case with many fixed-growth species, do not respond as quickly after release as free-growth species such as yellow-poplar. The response to additional resources after CTR can continue further into the initial growing seasons for trees with a free growth pattern, because they do not have a preformed inner bud that limits shoot development (Oliver and Larson 1996). However, fixed-growth species can exhibit more rapid shoot elongation on a given site and less site-sensitivity compared to free-growth species over many growing seasons. CTR is intended to produce long-term results, and numerous studies have indicated that long-term growth of both fixed- and free-growth species increases with a more complete crown release.

Crown release affects the development of crop trees in four observable growth characteristics: height, dbh, crown width and length of clear stem (Miller 1997). Field trials on codominant northern red oak indicated that release treatments increased dbh and crown growth at any age, but height growth and clear stem development differed by stand age at the time of the release (Table 2). For 16 year-old northern red oaks, dbh growth increased 62 percent and crown diameter growth increased 149 percent due to release. Similar increases in dbh and crown growth were observed for 55- and 80-year-old oaks.

Height growth and clear stem development were similar for released and control oaks at age 16, but these characteristics were negatively affected by release for older trees (Table 2). A crop tree's

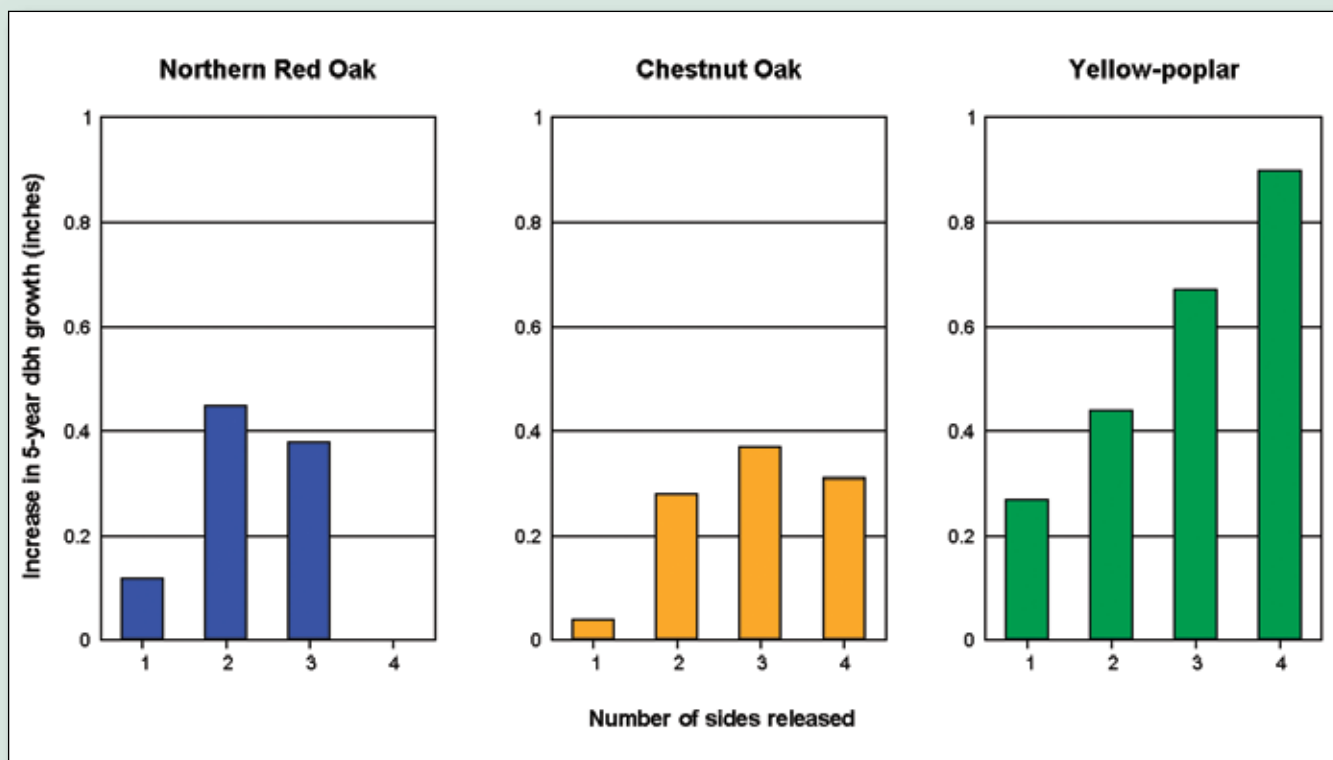


Figure 5. Dbh growth response for 54-year-old yellow-poplar, northern red oak and chestnut oak subject to one-, two-, three- and four-sided release compared to unreleased trees. No data for northern red oak released on four sides (Lamson et al. 1990).

Table 2. Annual growth of northern red oak 5 years after crop tree release (Miller 1997).

Age	Treatment	Height		Dbh		Crown diameter		Clear stem	
		Initial (ft)	Growth (ft/yr)	Initial (in)	Growth (in/yr)	Initial (ft)	Growth (ft/yr)	Initial (ft)	Growth (ft/yr)
16	Control	28.1	1.17	3.4	0.16	8.6	0.37	12.1	0.92
	Released	29.3	1.09	3.3	0.26	8.8	0.92	13.0	0.40
55	Control	84.8	1.43	15.2	0.21	22.9	0.30	43.4	0.40
	Released	84.4	0.52	15.1	0.28	24.9	1.10	44.2	-2.38
80	Control	102.6	0.26	22.7	0.21	43.4	0.27	48.7	0.31
	Released	101.5	0.02	23.7	0.31	41.7	0.76	46.1	-0.47



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Figure 6. *These 60-yr-old northern red oak crop trees were released on four sides. Ten years after CTR there is still free growing space available for their crowns to expand.*

height growth response to release is explained by how it captures unused growing space. Similar to other plants, trees tend to “reach” for additional growing space by expanding their crowns and roots. When the canopy is closed, lateral crown expansion is limited and the tree maintains its competitive position through height growth. When neighboring trees are removed, crown expansion shifts to lateral growth and height growth slows (Miller 2000). This response depends on stand age at the time of release. For example, in young sapling stands, gaps in the canopy resulting from the release close within seven to 10 years. Tree crowns expand laterally for a few years until the canopy closes and then normal height growth resumes. In older stands, release treatments result in larger canopy gaps; thus lateral crown expansion persists for longer periods compared to young stands (Figure 6).

Clear stem development is also affected by the longevity of canopy gaps. Gaps close quickly in

young stands after release, preventing the development of epicormic branches on the lower bole. In older stands, gaps persist longer and large branches can develop and actually reduce clear stem length.

The Recommended “Crown-Touching” Release

CTR is applied by increasing the growing space around the crowns of desirable trees (Lamson et al. 1990). The treatment entails eliminating trees that are limiting the horizontal crown expansion of the crop tree, thus increasing its free growing space. A “crown-touching” release is applied to deaden or fell adjacent competing trees whose crowns touch that of the crop tree (Figure 7). The increase in growing space provides more sunlight and belowground resources to the crop tree. The crop tree can then develop more leaf area in its crown, increasing photosynthesis and growth. Improved vigor and crown size also have the potential to improve seed production of

individual trees (Healy et al. 1999; Johnson et al. 2002).

CTR can be used to provide various degrees of release based on the proportion of the crown that is left free to grow (Figure 8). It is not necessary to remove or deaden adjacent trees whose crowns are beneath the crop tree, because they are not significantly interfering with the crown of the crop tree (Figure 9). In most cases, it is beneficial to retain trees in the overtopped and weak intermediate crown classes adjacent to crop trees. Such trees might be important for wildlife and aesthetics. They can also protect timber quality and value by shading the crop tree bole and reducing exposure to sunlight that can trigger epicormic branching. The key to effective CTR is to focus on identifying the desirable trees to favor, not the undesirable trees to eliminate.

Providing more than a crown-touching release in young stands can have an adverse effect on future merchantable log height and stem quality (Figure 10). Too much free growing space retards total height growth until the canopy gaps close and allows more time for epicormic branches to form and reduce clear stem development. Providing too much release also increases the risk of damage from wind, ice and wet snow, because the crop tree has little support from its distant neighbors. A simple

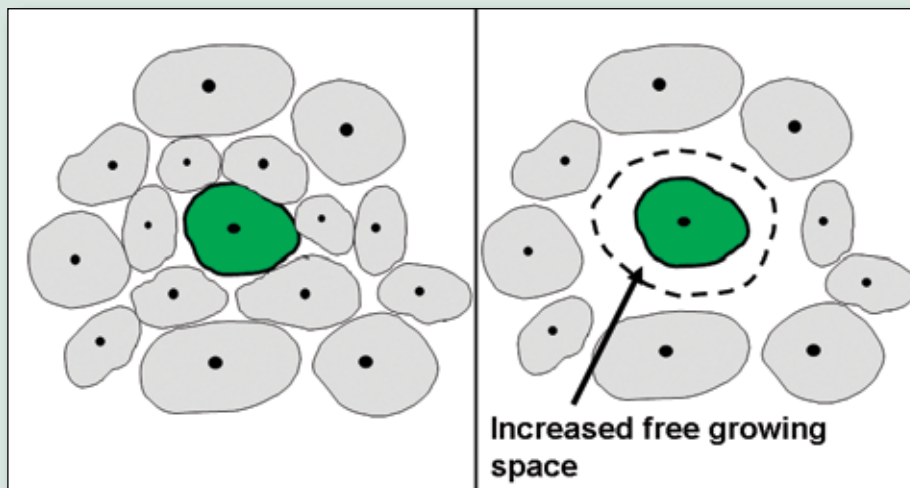


Figure 7. A crop tree crown (green) shown from above the forest canopy. The left diagram represents a crop tree crown before release with six adjacent competitors. The right diagram illustrates the free growing space available when a crown-touching release is applied to remove competing trees from all sides of the crop tree.

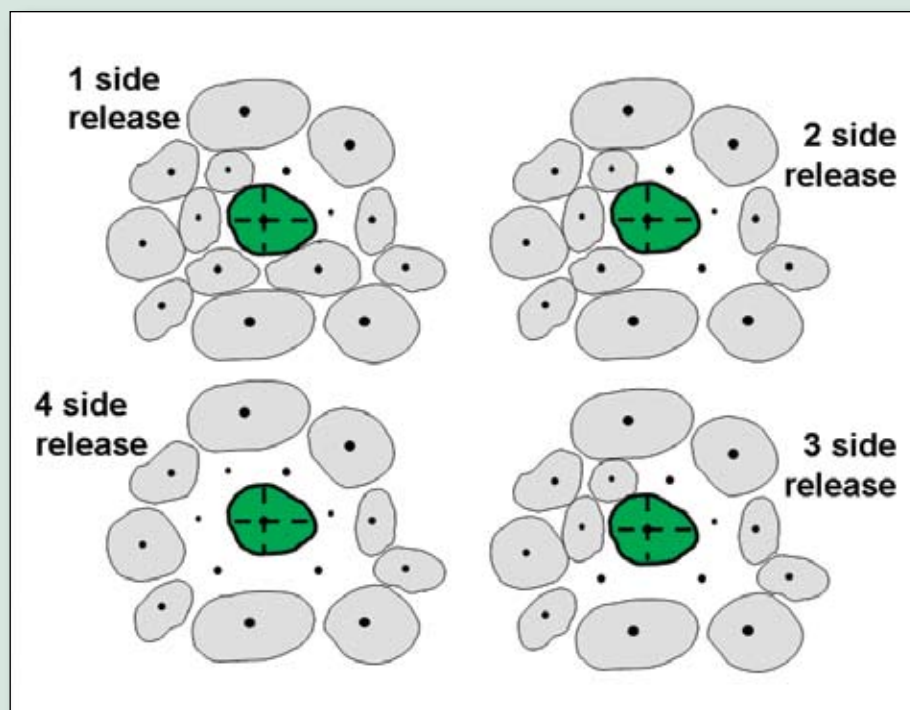


Figure 8. A crop tree crown (green) shown from above the forest canopy. The diagrams illustrate a partial and full crown-touching release where one, two, three or all four sides of the crop trees are released.

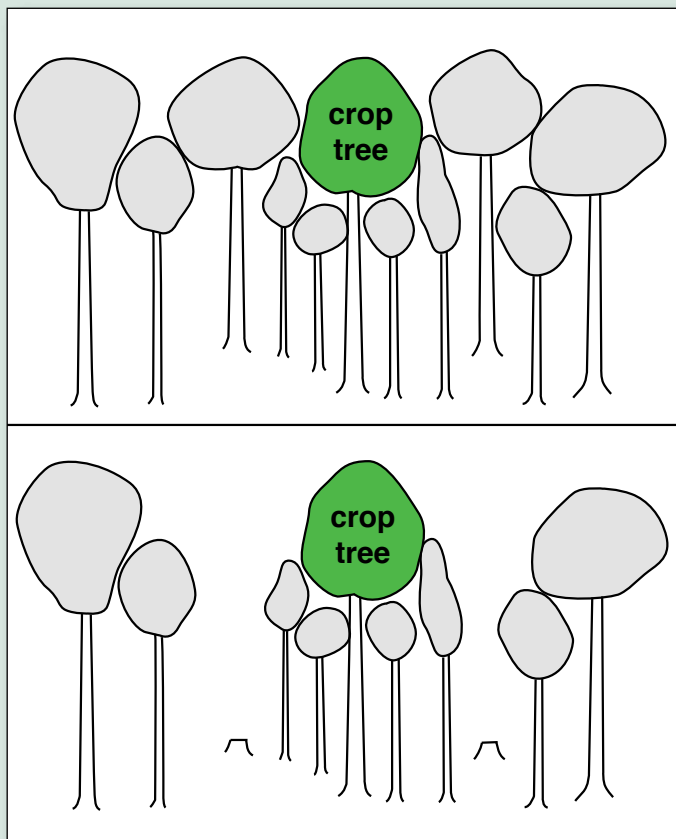


Figure 9. Subordinate trees in overtopped or weak intermediate crown classes need not be removed to release crop trees.



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Figure 10. This crop tree has too much free growing space. A crown-touching release removes only adjacent trees whose crowns touch that of the crop tree.

crown-touching release provides a good tradeoff between free growing space to enhance crop tree growth and quick canopy closure to maintain height growth and clear stem development.

Based on research and practical operational concerns, the following crown-touching release guidelines will help improve the effectiveness of CTR treatments.

1. Full crown-touching release should be considered for rapidly growing species such as yellow-poplar and young trees in the sapling or pole stage of development.
2. Less than a full crown-touching release (at least three sides released) can be used for small saw-timber crop trees to limit the risk of epicormic branching where timber quality is a concern.

3. Sub-canopy trees should be retained around crop trees to protect them and add other benefits to the stand, unless they conflict with management objectives.

How Many Crop Trees to Manage?

Mature hardwood stands contain hundreds of trees/ac, but the trees in the overstory account for the vast majority of stand volume and value (Figure 11). Data from a 53-year-old hardwood stand in the central Appalachians illustrate this important characteristic (Table 3). This stand regenerated naturally after clearcutting for charcoal in the 1930s with no interim silvicultural treatments or other disturbances. All trees (≥ 1.0 in dbh) in 20 0.5-acre permanent plots were tallied and assigned a stumpage value by species and merchantable volume based on local market prices. The trees were then ranked in order of increasing value in each plot

and the average per-acre results were computed for all 20 plots combined. The cumulative total of basal area, board foot volume and stumpage value were tabulated for the 70 most valuable trees/ac (Table 3). For example, the 10 most valuable trees/ac accounted for 15 percent of stand basal area, 32 percent of stand volume and 45 percent of stand value. The 20 most valuable trees/ac accounted for 63 percent of stand value. In addition, the overstory included 69 trees/ac in the dominant or codominant crown classes, and all of them were represented in the 70 most valuable trees/ac.

A closer examination of these data also indicated the importance of overstory species composition in determining stand value. For example, 56 percent of the stand value was found in only 20 overstory trees/ac (8 black cherry and 12 northern

red oak) (Figure 12.). The overstory had nearly twice as many yellow-poplar (36 trees/ac) that accounted for 37 percent of the stand value. Stand value was determined solely by natural competition for more than 50 years. The application of CTR treatments when the stand was still young, say age 10 to 20 years, would have increased the proportion of black cherry and red oak that survived in the overstory, thus increasing stand value at maturity.

This example illustrates that nearly all of the economic value in hardwood stands is found in a relatively small number of trees/ac. Forest managers need to focus on favoring all of the available crop trees, up to a maximum of 60 to 70 trees/ac. This upper threshold is determined by dbh/crown diameter relationships for each species (Lamson 1987; Miller et al. 2006). In rare cases, when there are more than 60 to 70 crop trees/ac, they can be released when the stand is still young and then some of them removed later in commercial thinning treatments. Hardwood stands usually contain less than the maximum number of crop trees recommended here, so most CTR prescriptions involve releasing a smaller, manageable number of crop trees/ac.



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Figure 11. Mature stands contain a maximum of 60 to 70 trees/ac in the dominant or codominant crown classes.

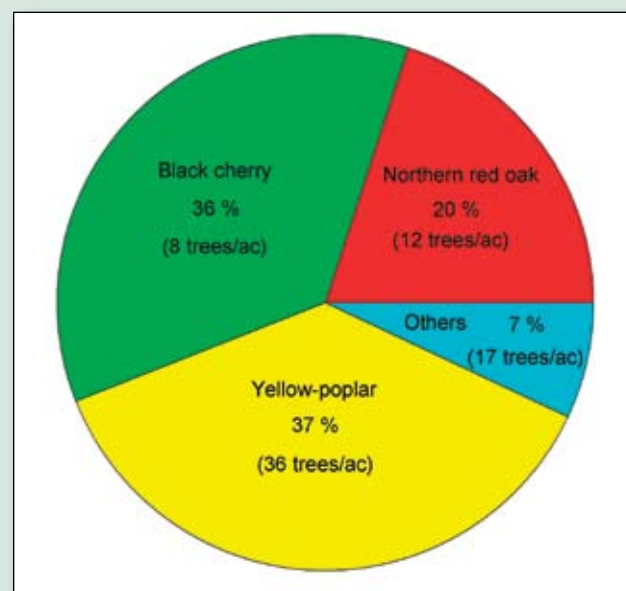


Figure 12. Distribution of stand value by species and number of merchantable trees/ac in each species group.

Table 3. Cumulative basal area stocking, merchantable volume, and stumpage value for the 70 most valuable trees/ac in a 53-year-old upland hardwood stand on site index 70.

Ascending Tree Value Ranking	Stocking	Volume ¹	Stumpage Value
No. trees/ac	percent of total		
10	15	32	45
20	26	53	63
30	34	69	76
40	41	80	86
50	48	89	93
60 trees	53 percent	95 percent	98 percent
70	58	99	99
Total 441	143 ft ² /ac	13.7 Mbf/ac	\$3,925/ac

¹ International 1/4-inch rule

Young Stands Contain More Crop Trees

For the first few years after a disturbance, thousands of small seedlings and sprouts per acre compete for the free growing space, but the strongest competitors become apparent in just a few years. When the stand is about 10 to 15 years old, overstory trees in the new stand form a closed canopy, and less than 3000 trees/ac remain (Figure 13). Although the young stand contains thousands of trees, only trees in the dominant and codominant crown classes are likely to remain competitive for many years.

Data collected from 18 even-aged, mixed hardwood stands in the central Appalachians illustrate typical hardwood stand development (Figure 14). These stands ranged from 9 to 36 years old on northern red oak site index 65 to 70, and they originated from complete overstory removal in 12- to 30-acre stands. No silvicultural treatments were applied after the stands formed, so the data represent only natural regeneration and development. On average, 15-year-old stands contained about 1,500 trees/ac (≥ 1.0 inch dbh), but only one-third of those were dominant or codominant (Figure 14, top and middle graphs, respectively). The total number of trees (Figure 14, top graph) and the number of dominant or codominant trees (Figure 14, middle graph) declined with increasing stand age.



Figure 13. This 12-year-old mixed hardwood stand on northern red oak site index 70 contains more than 80 crop trees/ac. The number of crop trees will quickly decline as the stand ages unless CTR is applied.

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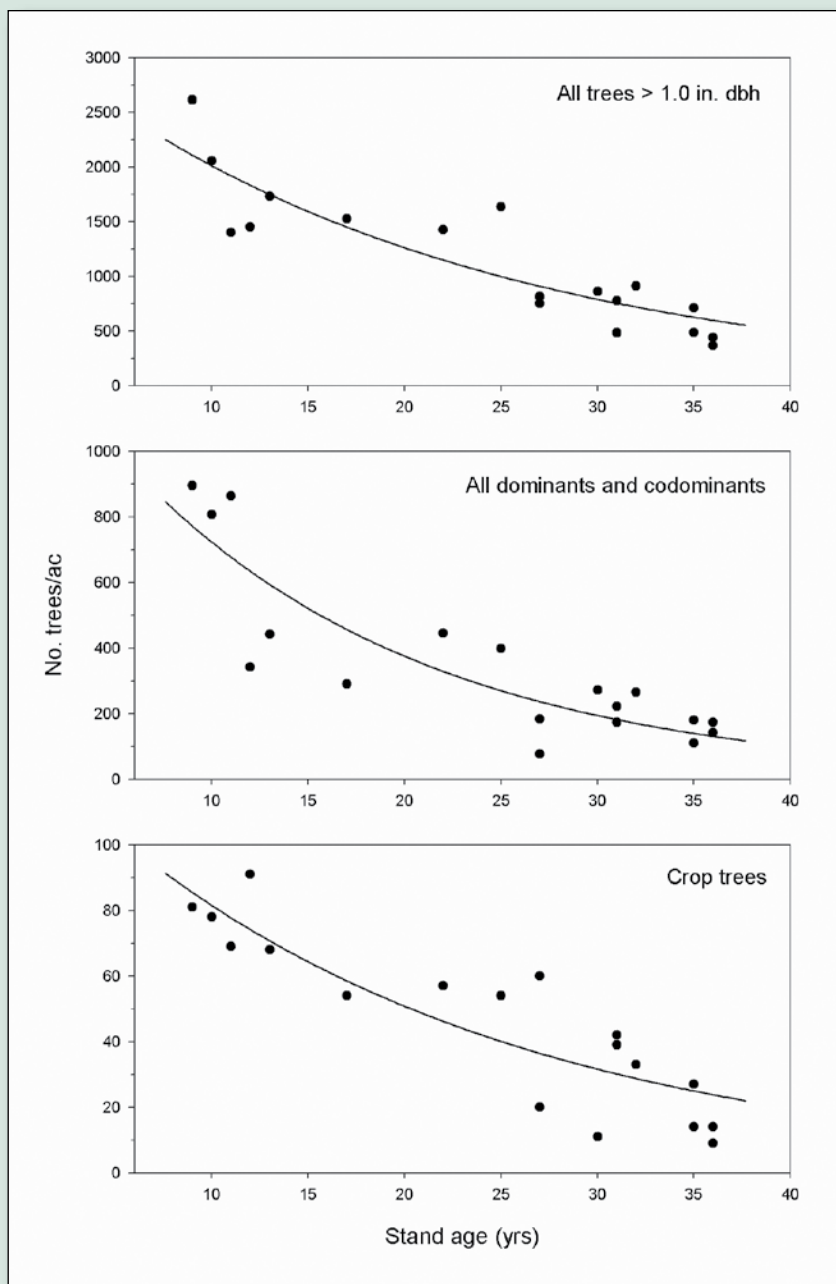


Figure 14. Number of trees per acre by stand age in mixed hardwood stands on northern red oak site index 65 to 70 in the central Appalachians. Note that the scale of the y-axis is different for each graph.

Management Objectives and Potential Crop Trees

Crop trees are defined by management objectives centered on market value, wildlife value, aesthetic value or “diversity” value. Species and quality are key characteristics in identifying potential crop trees. Only a small percentage of dominant and

codominant trees qualify as crop trees. In this example, potential crop trees met two requirements pertaining to species and quality. They included northern red oak, white oak, black oak, chestnut oak, black cherry, yellow-poplar, white ash, sugar maple and hickory. They also exhibited characteristics that indicated good quality (straight, branch-free boles, no cankers, no low forks, good attachment to stumps, good vigor, healthy crown and bark development, etc.). While 15-year-old stands contained about 500 dominant or codominant trees/ac, only 65 of those (< 15 percent) qualified as potential crop trees (Figure 14, bottom graph).

It is important to recognize that the number of potential crop trees declines with stand age. Each year a few potential crop trees succumb to the natural thinning process. In the absence of CTR treatments, stands older than 25 years often contain less than 40 crop trees/ac (Figure 14, bottom graph). In any given stand, the management objectives can be even more restrictive than the general characteristics described here. As a result, Figure 14 probably overestimates the number of potential crop trees in most stands.

Guidelines for Number and Spacing

Forest managers often ask about the number and spacing of crop trees to consider in planning a release treatment. As the data in Figure 14 indicate, the number of potential crop trees/ac is usually relatively low at any age, and the number declines as the stand ages. A general guideline is to release all available crop trees up to a maximum of 60 to 70 crop trees/ac. In most cases, however, the CTR treatment will involve far fewer trees/ac (Figure 14, bottom graph).



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Figure 15. CTR can be used in conjunction with traditional thinning treatments. Apply traditional thinning to reach the appropriate area-wide residual stand density, and apply CTR at the same time to make sure selected crop trees receive at least a 3-sided crown release.

Guidelines for spacing are less precise. Hardwood stands that form from natural regeneration sources exhibit random patterns of crop tree distribution. The distribution of stored seeds and advance reproduction vary according to the distribution of parent trees in the previous stand. In addition, variability in soil depth and moisture and other microsite conditions lead to variability in competition among young trees. Within a species, genetic variability can also lead to random distributions in tree quality and vigor. Management objectives certainly vary from stand to stand, so the criteria used to select crop trees introduce yet another source of variation in the location of crop trees. All of these factors interact to produce a random distribution of crop trees. It is not unusual to find a clump of three or four crop trees growing in close proximity or individual crop trees scattered 50 to 100 feet apart. A general guideline is to focus on finding the best available crop trees, regardless of spacing, and provide them with an adequate release. Avoid releasing trees that do not qualify as crop trees just for the sake of achieving an even distribution, as this approach may not be an efficient use of resources. In rare cases where crop trees are abundant and dispersed throughout the stand, seeking an even distribution of crop trees is acceptable, so long as each crop tree receives an adequate release.

Timing of CTR Treatments

In young hardwood stands, the best time to apply CTR is when the canopy begins to close

and continues for about 10-15 years after canopy closure. The stand age at canopy closure varies with site quality. On high-quality sites, where abundant resources accelerate stand development, canopy closure can occur at about age 8 to 10 years. On poorer sites, where fewer species are competitive and stand development is somewhat slower, canopy closure can occur at about age 13 to 15 years. In older hardwood stands that are approaching large pole or small sawtimber size, there are still opportunities to release crop trees to improve vigor, growth and spacing as the stand matures. However, beyond age 25 or 30 years, the number of crop trees will continue to decline without CTR.

In sawtimber stands, CTR can be applied in conjunction with a commercial thinning operation, thus favoring selected crop trees and yielding timber sale revenue to offset other management costs (Figure 15). The problem with delaying CTR until operations are commercial is that the number of remaining crop trees can be greatly diminished in older stands. Ideally, CTR should be applied when the stand is younger to retain as many crop trees as possible in the overstory.

Planning CTR and Training Work Crews

An effective method for planning CTR treatments or training work crews is to set up a demonstration plot in the field. A 0.25-acre square plot (about 104 feet on each side) is sufficient to communicate key concepts and stimulate helpful discussions before the actual treatment is applied.

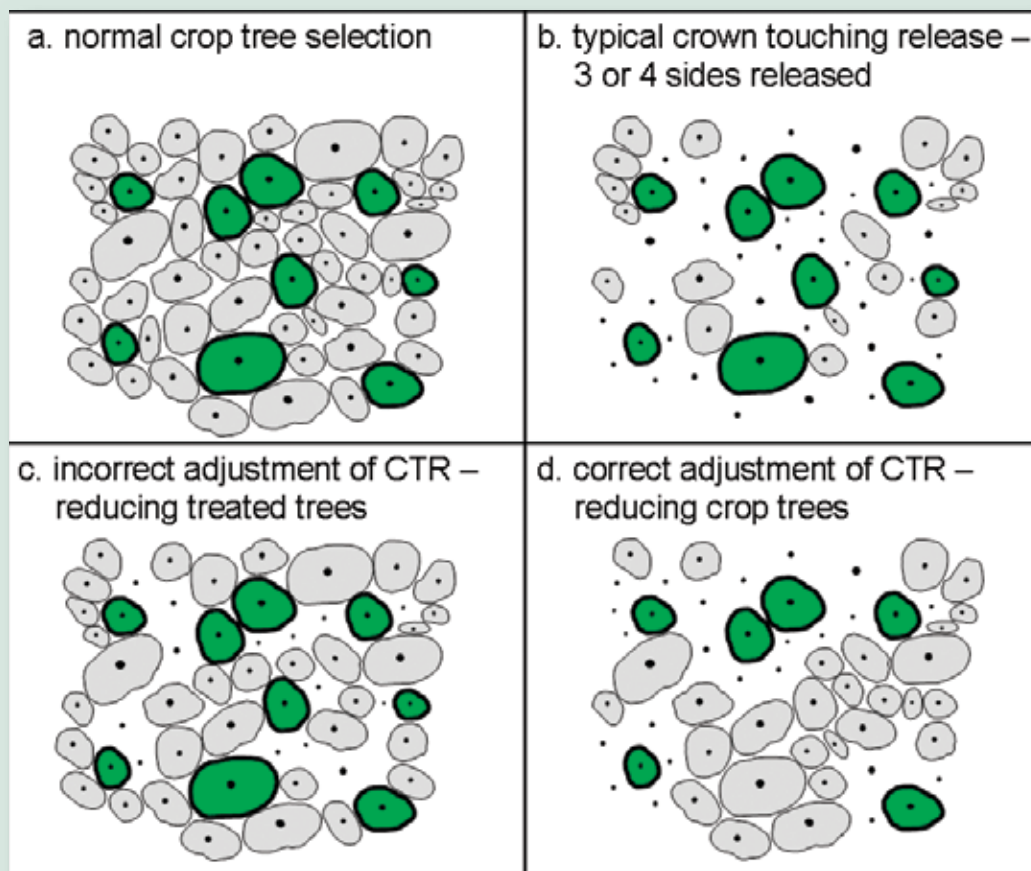


Figure 16. Adjust the stand treatment by altering the number of crop trees/ac, not the degree of release around each crop tree. For most efficient application of CTR, make sure each crop tree receives a 3- or 4-sided release.

Start by marking all crop trees within the plot with flagging of a particular color. Review the important characteristics of crop trees and emphasize that CTR is intended to help the best trees, not just reduce the number of undesirable trees. Emphasize that the objective is to eliminate adjacent trees so that each crop tree has free growing space. The next step in this planning/training process is to mark all trees to be eliminated with flagging of a different color. It is important to mark trees whose crowns touch that of the crop tree, but there is no need to mark subordinate trees. Once all the crop trees and their competitors are flagged in different colors, review the prescription and make sure all procedures and concepts are clear. The demonstration plot with trees marked in different colors displays the final outcome while there is still time to make changes.

Adjusting the Treatment

Occasionally, situations arise where the number of trees to be eliminated for a planned CTR is unacceptable to the landowner or forest manager. This can occur when landowners are unfamiliar with CTR and wish to take a light-handed approach until they gain more experience. It can also occur

where specific stand conditions or objectives require stocking levels greater than that provided by a typical CTR. Regardless, it is important to provide the proper degree of release for the best crop trees and ensure that CTR remains effective, even if it involves releasing fewer crop trees. Figure 16 provides an example of how CTR should be adjusted to reduce the number of cut or deadened trees. Figure 16a shows an untreated stand with crop trees identified according to management objectives. Figure 16b shows the stand after a 3- or 4-sided crown-touching release. Figure 16c shows an improper reduction in cut or deadened trees by providing less release to each crop tree. Figure 16d shows the proper procedure, simply reducing the number of crop trees, but still providing each crop tree with a full crown-touching release. The latter method focuses site resources on the best crop trees and assures that the investment in CTR provides the maximum benefit.

Marking the Stand

In actual field applications of CTR, there is no need to mark both the crop trees and the trees to be eliminated. Foresters have several options for preparing a stand for CTR. One option is to mark only

the crop trees, and allow the work crew to cut or deaden all the crown-touching competitors in a subsequent operation. Another option is to mark only the crown-touching competitors, and instruct the work crew to cut or deaden all the marked trees. A third option is to develop the abilities of work crews so they can identify crop trees and eliminate their competitors in one operation, thus eliminating the need for stand marking. The third option requires a training period using the first or second marking option and close supervision until work crews gain the necessary experience. Once work crews are properly trained, the forester need only direct them to the proper stand and provide specific guidelines for selecting crop trees.

Application Techniques

Generally, only top kill is required to effectively release crop trees, and there are a number of useful mechanical and chemical methods that can be used. Cutting competing trees with a chainsaw or brush saw is suitable when the number of trees to eliminate is relatively low. However, felling trees can be extremely difficult in sapling stands with a large number of competing trees. The cut trees often hang on adjacent trees, thus requiring time-consuming efforts or making the stand difficult to navigate. If cutting is used, no herbicide is required unless there is a need to prevent resprouting of cut stems. The sprouts from cut trees usually are not capable

of growing back into the canopy due to lack of sufficient sunlight or browsing by deer. Cut stumps can also be treated with herbicide to prevent resprouting of an exotic invasive species or to reduce undesirable stems that might be a nuisance in later regeneration phases.

In precommercial CTR, it is generally more cost effective to deaden competing trees and leave them standing. Some species, especially oaks, can be top-killed with a single 1-inch-deep chainsaw girdle (Mercker 2004). However, when girdling is used, it usually involves a double girdle 1 inch deep and spaced approximately 6 inches apart. It is best to do this treatment during late winter and early spring during sap rise. Diffuse porous species, especially those with well-developed crowns that signal high vigor, are poor candidates for girdling without herbicides. Such trees have the ability to callus and re-establish inner phloem across the girdles. Allowing competing trees to survive severely reduces the effectiveness of CTR because it results in an incomplete crown release, less than optimal crop tree response and lower returns on invested resources.

In most stands, competing trees can be effectively controlled using herbicides. Cut-surface methods such as hack-and-squirt or basal tree injection can be used to administer herbicides through an incision in the bark (Figure 17). Basal bark treatments can also be used when competing trees are < 6 inches dbh. The herbicides will provide both

Figure 17. Hack-and-squirt is a target-specific CTR method that places a measured amount of herbicide into competing trees through small incisions in the bark.



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top and root kill and should be considered for use when problematic species are to be eliminated. Several common herbicides such as glyphosate, triclopyr or imazapyr formulations can be used in CTR operations, but the specific circumstances of each job should be considered in selecting the appropriate herbicide. Always read the product label and follow all precautionary recommendations on the label. Consult published information about using herbicides in CTR treatments (Kochenderfer et al. 2001; Jackson and Finley 2006.)

Herbicides can damage crop trees if they are used improperly. Crop trees can be harmed from either the uptake of herbicides from the soil or translocation of chemicals through root grafts, referred to as flashback. Flashback is of particular concern when competing trees are the same genus as the crop trees. Root grafting between trees of the same genus is thought to be more pronounced in rocky soils and when trees are in close proximity to one another. Research has clearly indicated flashback potential for several upland oak species, black walnut, red maple and American beech. Occasionally, yellow-poplar has been damaged by flashback when competing trees are very close to the crop trees. No known instances of root graft transmittance have been observed among species of different genera. Occasionally, use of herbicides that exhibit soil activity can also damage crop trees. Transmission of soil-active herbicides can be particularly problematic when the treatment involves many trees/ac and the soils are fairly porous. In summary, if the competing trees and crop trees are of different genera or the selected herbicide does not exhibit soil activity, then there is minimal risk of injury to the crop trees.

Risks Associated with Crop Tree Release

In general, CTR reduces the inherent long-term risk to standing timber in several ways. Drought, wind, ice, lightning, insect attack and various pathogens can be potential agents of harm to desirable crop trees. Released trees develop larger root systems, thus increasing their resilience to adverse moisture conditions or wind. They also develop larger crowns and increased capacity to recover from crown damage due to insects, ice or wind. CTR also reduces crowding in overstocked stands, and this improves overall stand vigor and resistance to damaging agents.

Table 4. Susceptibility to epicormic branching among hardwood species (Trimble 1975).

Abundance of sprouts	Species
Very many	White oak, Northern red oak
Many	Basswood, Black cherry, Chestnut oak
Few	American beech, Hickories, Yellow-poplar, Red maple, Sugar maple, Birches
Very few	White ash

Although most effects of CTR are positive, there are some temporary negative effects as well. Most CTR risk can be controlled by limiting the treatment to a simple crown-touching release. If the release provides too much free growing space, epicormic branching can form on the lower bole of the released crop tree. These branches can reduce both form and grade, and lead to a reduction in future market value. Table 4 summarizes the propensity of certain species to produce epicormic branches upon excessive release (Trimble 1975).

Other risks associated with too much free growing space include wind throw and damage from snow and ice. Prior to release, crop trees in the overstory have physical support from their neighbors to stabilize them against heavy snow and ice or bursts of wind. CTR removes adjacent trees, thus briefly leaving crop trees vulnerable to these damaging agents. In commercial stands, crown-touching release produces much larger canopy gaps that take much longer to close. In high-risk locations, CTR in commercial stands can be limited to two sides around each crop tree. Also, maintaining the appropriate residual stand stocking in commercial stands will limit the risk from snow, ice and wind (Gingrich 1967).

Fluctuation in market value is another form of risk associated with CTR. Some species have remained relatively valuable for decades, while others have exhibited less reliable long-term trends. For example, Appalachian kiln-dried 4/4 #1C red oak lumber increased 10.9 percent in a 24-month period beginning in October 1996, and then it decreased

by 8.6 percent over a similar period beginning in March 2000 (Hardwood Market Report 2007). Price volatility is an important factor to consider in applying CTR, but there are a few strategies to reduce such risk. First, select a diversity of species as crop trees to reduce the risk of declining prices for any one species. Second, select crop trees with desirable form and potential grade so that the mature trees will have maximum value for each species. Third, avoid investing in marginal trees that don't meet the criteria for crop trees. Limiting investments to fewer trees/ac reduces the overall cost of CTR and it assures that resources are focused on those trees that are most likely to provide desired returns and benefits in the future.

Economic Feasibility of CTR

Precommercial CTR requires an investment of time and money, so it is important to apply such treatments only in stands where the potential benefits exceed the costs. Improving the proportion of high-value species and high-quality trees in the overstory is the primary justification for applying CTR in young hardwood stands. Other benefits include faster dbh growth and perhaps improved stand quality. Potential benefits are best in stands where high-value crop trees (due to species or quality) are threatened by aggressive, low-value competitors. The process of recognizing candidate stands for CTR or prioritizing treatments among multiple stands begins with a relatively simple inventory of the crop trees.

Collecting Data

Collect data on crop trees and their competitors within each stand. Small, fixed-area circular plots work well in young hardwood stands, but any reliable sampling system is acceptable. Each plot is 0.01-ac (11.8 ft radius) for stands 10-15 years old, or 0.02-ac (16.7 ft radius) for stands 15-20 years old. The appropriate plot size should capture the structure of the overstory trees and account for variability within the stand. Measure one plot for every acre up to 10 acres, then one plot for every other acre, i.e., 10 acres = 10 plots, 20 acres = 15 plots. Stands with high variability may require more plots. Note that the number of crop trees among plots can vary, and some plots may contain none at all.

Within each plot, record the species and competitive status code for each crop tree based on its crown class and the relative aggressiveness of its adjacent competitors. This step requires an understanding of site quality and how it affects competitive interactions among species. The purpose of this

step is to assess the likely effect of CTR on the each crop tree's long-term ability to compete. Later, this information will be aggregated for all crop trees in the stand to determine the likely impact of CTR on future stand value. A brief definition of each competitive status code follows.

Competitive Status Codes

- 1 – Dominant or strong codominant crop trees that are likely to survive without release. These trees are often of vigorous seedling-origin or aggressive sprout-origin trees that are expected to compete well without CTR.
- 2 – Codominant crop trees that are not immediately threatened by adjacent trees. These crop trees are flanked by trees of the same height and crown size. They might be threatened in the future if neighboring trees becomes more aggressive. These crop trees will become strong codominants if released.
- 3 – Weak codominant crop trees that are threatened by adjacent trees and are not likely to remain competitive in the main canopy without release. Neighboring trees are usually larger, fast-growing trees or aggressive sprout clumps. These crop trees can remain codominant if released in the near future.
- 4 – Desirable crop trees in the intermediate crown class. Crown vigor indicates that such trees are still capable of responding to release, but CTR is needed immediately to prevent further decline. Examples include shade-tolerant maples or mid-tolerant oaks. The proportion of trees with this competitive status that can become codominant as a result of CTR depends on initial vigor and height differential when released.

Also record the species and origin of competing trees within each plot, but be careful not to double-count competitors whose crowns compete with more than one crop tree. Competing trees are adjacent to the crop trees, their crowns touch that of the crop tree and they are usually dominant or codominant crown class. The purpose of this step is to determine the species most likely to replace crop trees if they are not able to remain competitive in the overstory. Information about the species and origin of competing trees is also useful in planning herbicide or mechanical release methods. Note that plots with no crop trees also have no competitors to record.

Summarizing Data

The first step in summarizing the data is to tabulate the number of crop trees per acre and to stratify them according to their competitive status. The data presented in Table 5 illustrate an inventory from a 16-yr-old hardwood stand on SI 70. The crop trees include northern red oak, white oak and black oak. The stand contains 22 northern red oak crop trees/ac, but their competitive status varies. As a result, not all of them are expected to survive

or remain competitive in the overstory as the stand matures. CTR can be applied to increase their competitiveness and long-term survival. For example, about 90 percent of crop trees with competitive status 1 are expected to survive without CTR and about 95 percent are expected to survive with CTR. Appropriate survival rates are applied for all levels of competitive status and the results are summed. Note that the probability of survival decreases as competitive status declines, but it increases when

Table 5. Crop tree inventory and estimated long-term survival in the overstory with and without CTR treatment.

CT Species	Competitive Status	CT Inventory	Survival Without CTR		Survival With CTR	
		no./ac	percent	no./ac	percent	no./ac
Northern red oak	1	3	90	2.7	95	2.8
	2	6	50	3.0	90	5.4
	3	6	25	1.5	50	3.0
	4	7	5	0.3	10	0.7
Sub total		22		7.5		11.9
White oak	1	2	90	1.8	95	1.9
	2	5	50	2.5	90	4.5
	3	8	25	2.0	50	4.0
	4	6	5	0.3	10	0.6
Sub total		21		6.6		11.0
Black oak	1	4	90	3.6	95	3.8
	2	8	50	4.0	90	7.2
	3	6	25	1.5	50	3.0
	4	2	5	0.1	10	0.2
Sub total		20		9.2		14.2
Grand total		63		23.3		37.1

CTR is applied. For northern red oak crop trees, 7.5 crop trees/ac are expected to survive without CTR and 11.9 crop trees/ac are expected to survive with CTR (Table 5). This estimation procedure was repeated for white oak and black oak. While the stand contained 63 crop trees/ac based on the inventory, only 23 crop trees/ac will survive without CTR, and 37 crop trees/ac will survive with CTR (Table 5, bottom row).

There is not an abundance of information available to estimate how CTR affects survival rates for various levels of competitive status. Survival rates for northern red oak were obtained from Ward and Stephens (1994), but little is known about other species. The survival rates presented in Table 5 are general estimates obtained from numerous sources, but they can be adjusted based on local conditions and professional judgment.

Benefits of CTR

Once the inventory data are used to project crop tree survival (Table 5), it is possible to estimate the economic benefit of CTR in terms of its effect on future stand value. For this example, it is assumed that merchantable volume will be 9.0 Mbf/ac (Doyle rule) comprising 70 merchantable overstory trees/ac when the stand is mature. The mature stand will also contain hundreds of unmerchantable trees/ac beneath the overstory, but they have little influence on stand value. Also, increases in volume or quality from CTR are not considered here. This simple example considers only the effect of CTR on overstory species composition as it relates to stand value.

CTR increases stand value by increasing the proportion of high-value crop trees and reducing the proportion of low-value competitors. The number of crop trees in the overstory at maturity was estimated in Table 5. The remainder of the overstory will

Table 6. Effect of CTR on overstory composition and stand value.

Merchantable Trees	Price	Composition and Value Without CTR			Composition and Value With CTR		
	\$/Mbf	no./ac	percent	\$/ac	no./ac	percent	\$/ac
Crop Trees							
Northern red oak	450	7.5	10.7	433	11.9	17.0	689
White oak	550	6.6	9.4	465	11.0	15.7	777
Black oak	350	9.2	13.1	413	14.2	20.3	639
Sub total		23.3	33.2	1,311	37.1	53.0	2,105
Competitors							
Red maple	115	23.3	33.3	345	16.4	23.4	242
Other	90	23.4	33.4	271	16.5	23.6	191
Sub total		46.7	66.7	616	32.9	47.0	433
Grand total		70	100		70	100	
Stand Value				\$1,927			\$2,538

Stumpage volume at maturity = 9 Mbf/ac (Doyle rule). Stumpage prices for grade 1 sawtimber trees \$/Mbf (Doyle rule).

be occupied by red maple and other competitors. Table 6 illustrates the effect of such tradeoffs on stand value. For example, crop trees are expected to occupy 33.2 percent of the overstory (23.3 trees/ac) without CTR and 53.0 percent of the overstory (37.1 trees/ac) with CTR. Similarly, competitors will occupy 66.7 percent of the overstory (46.7 trees/ac) without CTR and only 47.0 percent of the overstory (32.9 trees/ac) with CTR. In either case, the overstory in the mature stand comprises 70 trees/ac. The benefit of CTR is a greater proportion of high-value crop trees at maturity.

The stand value with and without CTR was then estimated by applying stumpage prices to the proportion of the stand occupied by each species. For example, the stumpage value of northern red oak is \$433/ac without CTR. This was obtained by multiplying the stumpage price (\$450/Mbf) times the stand volume (9 Mbf/ac) times the proportion of northern red oak (10.7 percent). Similarly, the value of northern red oak is \$689/ac with CTR. This procedure is repeated for each species and the results summed. As a result, the projected stand value is \$1,927 without CTR and \$2,538 with CTR. The increase of \$611/ac is a conservative estimate of the economic benefit of CTR, because it includes only the benefits of improved species composition. A more sophisticated analysis would also include benefits such as improved tree quality resulting from CTR.

Is CTR Economical?

The example presented in Tables 5 and 6 provides a simple method for computing the potential benefit of CTR in a given stand, but the benefit is only one part of the analysis; the cost is equally important. In most applications, the average cost of precommercial CTR can vary from \$40 to \$60/ac, depending on number of crop trees/ac, access, terrain, methods, and wage rates (Stringer et al. 1988). In addition, the benefits of CTR applied in young stands take many years to accrue, thus an investment period of 30 to 40 years is quite possible. For this example, an investment of \$50/ac in CTR, resulting in a \$611/ac increase in stand value over 40 years, represents a 6.5 percent annual real rate of return. CTR appears to be a very good investment in this example. Reductions in cost from assistance programs or do-it-yourself treatments would further enhance the rate of return.

The economic feasibility of CTR can vary dramatically, because each stand has somewhat unique characteristics. The greatest economic benefits are

possible in stands where there is a large difference between the value of crop trees and their competitors due to species or quality. In addition, crop trees with competitive status 2 and 3 offer the greatest rewards because CTR can enhance their long-term competitiveness. Assessing economic feasibility in individual stands is relatively simple compared to larger forests involving multiple stands. Keep in mind that calculating potential rate of return for CTR is an estimate. Response among species on a particular site and future market values can add variability to the estimate. Forest managers who are responsible for managing dozens of stands should analyze each stand individually, prioritize them by potential rate of return and apply CTR on the most promising stands first.

Guidelines for Contractors – Improving Efficiency

Forestry contractors who engage in CTR must apply techniques that are cost-effective. Labor accounts for the greatest proportion of cost in a CTR project, and the method employed to eliminate competing trees can affect the production rate. The key to improving efficiency is to minimize the combined costs of labor, tools, fuels or chemicals needed to eliminate competing trees and to avoid return visits. For example, for ring-porous species, a simple girdling operation probably costs less than an operation involving herbicides (Table 7). However, diffuse-porous species may not succumb to girdling treatments, so an herbicide treatment method may be a more cost-effective approach because it eliminates competing trees in one visit. If root-grafting among trees is a problem or if crop trees are primarily found in sprout clumps, herbicides may not be a suitable option. In such complex cases, felling the competing trees might be the best option. Access, terrain, distance to the job site, understory density, season of the year and stand age are also important factors that affect project cost. Each stand has unique characteristics that influence cost-effectiveness, so contractors should be flexible in the tools and methods used to apply CTR; one size usually does not fit all.

Combining Associated Silvicultural Practices

CTR can be applied in even-aged, uneven-aged or two-aged stands. The simplest form of CTR takes place in even-aged stands or in groups of trees that are about the same age, as is typical in group selection or patch cutting practices. In more complex stands, the crop trees may differ in age, but the

principles are the same. The crown-touching release is intended to enhance the development of preferred trees based on their ability to meet management objectives. CTR can also be applied in combination with other silvicultural practices such as vine control, salvage operations or eradication of invasive plants. Planning combined treatments improves efficiency because work crews can avoid the cost of making return visits for individual treatments. Here are few examples of combined treatments.

Uneven-aged stands managed by group selection have trees in various stages of development, so they often require several simultaneous treatments to achieve stand-level objectives. For example, one part of the operation might involve harvesting mature trees to create sizeable canopy gaps in which new reproduction can become established and develop. A second part of the operation might involve CTR in older gaps that contain cohorts of saplings from a previous harvest. A third part of the operation might involve CTR between the gaps to promote faster growth of immature sawtimber until it can be removed later. And a fourth operation might involve vine control to prevent damage to young reproduction.

Nonindustrial private forests often contain complex stands where multiple cohorts of trees have regenerated after diameter-limit harvests every 15 or 20 years. Such stands have some good trees, some poorly formed trees and decadent trees that have been left time and again after several harvests. CTR can be quite effective in such stands as a means of saving the few good trees that remain. One part of the operation might involve CTR for immature trees whose competition is of similar height and age. A second part of the operation might involve CTR for immature trees whose competition is older and taller. A third part of the operation might involve controlling low interfering brush that prevents desirable advance reproduction from developing. A final part might involve herbicide treatments to eradicate an invasive tree or shrub.

When any stand treatment is considered, there can be an opportunity to apply CTR at various scales to improve future stand conditions. The tools, materials and skill level required for CTR are often the same as those required for other silvicultural treatments. Combining other practices with CTR makes more efficient use of time and avoids the added expense of repeated visits to the site.

Table 7. Wood characteristics by species (Perkey et al. 1994).

Ring-porous	Diffuse-porous ¹
Ash	Aspen
Black cherry ²	Basswood
Elm	Beech
Catalpa	Birch
Chestnut	Blackgum
Coffeetree	Buckeye
Hackberry	Cottonwood
Hickory ³	Cucumber
Locust	Dogwood
Red mulberry	Hemlock
Oak	Holly
Osage-orange	Hophornbeam
Persimmon ²	Hornbeam
Sassafras	Maples
Walnut ²	Pines
	Sourwood
	Spruces & firs
	Sweetgum
	Sycamore
	Yellow-poplar

¹ Diffuse porous species may be resistant to girdling treatments and may require the use of herbicides for effective control.

² These species are semi-ring porous.

³ Bitternut hickory is semi-ring porous, but other hickories are ring-porous.

Summary – Key Concepts to Consider in Applying CTR

- Clarify your management objectives first. The criteria for selecting crop trees depend on your management objectives. The crop trees are those few trees/ac that produce desired benefits now and in the future.
- Crop trees must be able to compete successfully after release in the forest community and live long enough to provide benefits that meet management objectives; thus crop trees are usually found in dominant or codominant crown classes. Trees in intermediate or suppressed crown classes, particularly shade-intolerant species, generally do not respond well to CTR.
- Provide crop trees with a “crown-touching” release, no more and no less. Any competitor whose crown touches that of the crop tree should be eliminated. The competitors in subordinate crown classes beneath the crown of the crop tree need not be eliminated.
- Release up to 60-70 crop trees/ac. Release only the trees that meet your crop-tree selection criteria. Investing in the release of substandard crop trees is an inefficient use of resources.
- If possible, apply CTR early in stand development, at or near the time of canopy closure, to maximize the number and distribution of available crop trees/ac.
- CTR is most economical in stands where there is a large difference in the value between the crop trees and their competitors due to species or quality.
- Use demonstration plots to communicate desired procedures and clarify instructions. Train work crews to focus on identifying the desirable crop trees to favor, not the undesirable trees to eliminate.
- Focus on identifying the best available crop trees, regardless of spacing, and provide them with an adequate release. Following an arbitrary spacing rule can lead to inefficient investments in substandard trees.

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Although CTR leads to faster diameter growth and shorter rotations for desired products, the greatest economic benefit of CTR results from increasing the proportion of high-value species and high-quality crop

Crop trees must be able to compete successfully after CTR and live long enough to provide benefits that meet long-term management objectives. Crop trees are usually found in dominant or codominant crown classes. Trees in intermediate or suppressed crown classes generally do not respond well to CTR and should not be selected as crop trees.

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