EXPLORING THE OPTIMAL ECONOMIC TIMING FOR CROP TREE RELEASE TREATMENTS IN HARDWOODS: RESULTS FROM SIMULATION

Chris B. LeDoux and Gary W. Miller[1]

Abstract.—In this study we used data from 16 Appalachian hardwood stands, a growth and yield computer simulation model, and stump-to-mill logging cost-estimating software to evaluate the optimal economic timing of crop tree release (CTR) treatments. The simulated CTR treatments consisted of one-time logging operations at stand age 11, 23, 31, or 36 years, with the residual stands projected to their optimal economic rotation. The logging costs and revenues were estimated for the initial entry and for harvest at the optimal economic rotation. For comparison, the cost of CTR using hack-and-squirt herbicide treatments were computed as an alternative to the logging treatments at each age. The rotation age and final harvest were assumed to be the same for the logging and herbicide alternatives. The cumulative present net worth was used to compare the alternatives. When the rotation age was held constant at 100 years, the optimal economic timing for CTR using ground-based logging systems began at about age 27 and continued until about age 36. For the herbicide method, the optimal economic timing for CTR started at about age 20 and continued to about age 34. The results are useful to forest managers, landowners, and policy makers when considering CTR treatments in young hardwood stands.

INTRODUCTION

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, esthetic 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 (Perkey and others 1994, Perkey and Wilkins 2001).

CTR is applied by increasing the growing space around the crowns of desirable trees (Lamson and others 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, fell, or harvest adjacent competing trees whose crowns touch that of the crop tree. The increase in growing space provides more sunlight and belowground resources to the crop tree. The crop tree then develops more leaf area in its crown, thus increasing photosynthesis and growth.

Traditional thinning techniques 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, in reality CTR can be applied to trees that will be

[1]Industrial Engineer (CBL), Northern Research Station, USDA Forest Service, 180 Canfield Street, Morgantown, WV 26505; and Research Forester (GWM), Northern Research Station, USDA Forest Service, 180 Canfield Street, Morgantown, WV 26505. CBL is corresponding author: to contact, call (304)285-1572 or email at cledoux@fs.fed.us.

either harvested in the future or retained for any number of years, depending on how they provide desired benefits or meet management objectives.

In young hardwood stands, the availability of crop trees is greatest when the canopy begins to close and continues for about 10-15 years after canopy closure. Young stands at canopy closure often contain in excess of 70 crop trees per acre, more than enough desirable trees to meet long-term management objectives. 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.

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 30 to 40 crop trees per acre. In slightly 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. However, beyond age 25 or 30 years the number of crop trees will continue to decline without CTR.

The timing of CTR treatments presents an important economic tradeoff between treatment cost and long-term benefit. Young stands contain the maximum number of desirable trees and the maximum opportunity to favor crop trees capable of increasing long-term stand value. However, young stands offer little merchantable wood volume to reduce treatment cost and they result in relatively longer investment periods (years until rotation age). Conversely, older stands contain bigger trees with more merchantable volume and relatively shorter investment periods. The problem with delaying CTR until operations are commercial is that the number of remaining crop trees can be greatly diminished in older stands, thus reducing the potential benefits of CTR. The tradeoff between cost and benefit in young stands leads to a critical management question: What is the optimal economic timing for CTR treatments?

OBJECTIVES

This report describes a method for exploring the optimal economic timing of CTR treatments in young Appalachian hardwood stands using stump-to-mill logging cost software integrated with a stand growth simulation model and discounted cash flow analysis. The results of this limited analysis indicate favorable stand ages for applying CTR and shed light on factors that affect the optimal timing of treatments.

METHODS

Stand Data

Data were obtained from 16 even-aged Appalachian hardwood stands, ranging in age from 11 to 36 years, on the Monongahela National Forest (MNF) in central West Virginia (Miller and others 2001). The stands were all located on the same ecological land type, defined by MNF personnel as the red oak series, and contained a mixture of upland hardwood species characteristic of northern red oak site index 70 on moderate 30- to 40-percent slopes.

Data from the 16 stands were stratified by age and stand structure was summarized at ages 11, 23, 31, or 36 years (Stands A, B, C, D). The summarized data included four stands at each age. For each age group, tree lists were developed to display total number of trees per acre (≥1.0 inches diameter at breast height [d.b.h.]), number of overstory trees per acre (only dominant and codominant crown classes), number of crop trees per acre (those trees that met species, vigor, and quality criteria), and number of harvest trees per acre (trees to be eliminated for the CTR treatment).

Species composition has a strong impact on economic returns in harvest operations, and even slight variability in species composition among the four groups of stands was a potential source of bias in exploring the optimal timing of CTR treatments. The distribution of the 81 crop trees found in the 11-year-old group was 30 percent yellow-poplar, 19 percent black cherry, 14 percent chestnut oak, 14 percent northern red oak, and 23 percent others. The number of crop trees averaged 56, 31, and 16/ac in the 23-, 31-, and 36-year-old stands, respectively. To provide for a valid comparison of economic returns among the four stand ages, the species composition (proportion of crop trees by species) for each age was adjusted to reflect the average species composition found in the 11-year-old stands. Similarly, the dominant and codominant trees competing with the crop trees in the 11-year-old stands were 3 percent yellow-poplar, 3 percent black cherry, 6 percent chestnut oak, 4 percent northern red oak, 15 percent red maple, 41 percent black birch, 4 percent pin cherry, 13 percent black locust, and 11 percent other commercial species. The species composition of competing trees also was adjusted to reflect that found in the 11-year-old stands.

LOGGING SYSTEM

The ground-based logging system assumed for the simulation was a John Deere 440 skidder (Deere and Co., Moline, IL) with chainsaw felling. The logging system remained the same for all simulations, including both CTR at various ages and the final harvest. The 70 horsepower JD 440C is considered a small skidder that is suited for skidding small-diameter logs such as those in the CTR treatment (LeDoux 2000, LeDoux 2007). The stump-to-mill logging costs were simulated for each treatment. It was assumed that no new road construction was needed, as the CTR treatments were simulated on sites that had been previously harvested. The one-way mileage to the sawmill or pulpwood plant was held constant at 25 miles. The logs were transported on traditional tandem trailer log trucks.

Model Used

MANAGE-PC (LeDoux 1986) integrates harvesting technology, silvicultural treatments, market prices, and economic returns over the life of a stand. The simulation combines discrete and stochastic subroutines. Individual subroutines model harvesting activities based on the silvicultural treatment, growth and yield projections, market prices, and discounted present net worth (PNW) economic analysis. MANAGE-PC was used to estimate volume yield, logging costs, logging revenues, and economic rotation length for each alternative.

The tree lists associated with CTR treatments at various stand ages were used as input to the simulation model and stand growth was projected in 5-year intervals until it reached its optimal economic rotation defined by the maximum PNW.

The delivered prices for sawlogs and pulpwood were obtained from forest products price bulletins (Ohio Agricultural Statistics Service 2007, Pennsylvania State University 2007, Tennessee Division of Forestry 2007, West Virginia University Division of Forestry 2007) and averaged by species (Table 1). Pulpwood and lower quality logs reflect prices paid for wood used to produce fiber products such as Oriented Strand Board. The cost for CTR treatments using herbicides was $0.91/ft^2 of basal area obtained from results of recent field trials (Kochenderfer and others 2001).

Table 1.—Delivered prices for sawlogs and fuelwood/pulpwood by species

Species	Product			
	Large[a] high-quality sawlogs	Medium[b] size and quality sawlogs	Small[c] low-quality sawlogs	Fuelwood[d]/ Pulpwood
	-----------$/Mbf (Int. ¼-inch)-----------			$/cord
Red maple	251	192	131	40
Red oak	561	397	225	40
Yellow-poplar	571	397	225	40
Black cherry	571	397	225	40
Chestnut oak	450	279	138	40
Black birch	200	180	150	40
Pin cherry	150	100	80	40
Black locust	150	100	80	40
Other noncommercial	150	100	80	40

[a]Minimum small-end diameter ≥13 in, length ≥10 ft.
[b]Minimum small-end diameter ≥11 in, length ≥8 ft.
[c]Minimum small-end diameter ≥10 in, length ≥8 ft.
[d]89 ft^3/cord, minimum small-end diameter ≥4.0 in that will not make large, medium, or small sawlogs.

Table 2.—Summary of stand structure and effect of CTR treatment by stand age

Inventory	Stand age when CTR applied (yrs)			
	11	23	31	36
	----------- number of trees/ac --------------			
All trees ≥1.0 inch d.b.h.				
Initial	1566	1324	735	518
Cut	367	218	143	106
Residual	1199	1106	592	412
Dominant and codominant trees only				
Initial[a]	648	320	229	153
Cut	275	118	93	70
Residual[a]	373	202	136	83
Crop trees	81	56	31	16

[a]Includes crop trees.

RESULTS

The pretreatment inventory (all trees ≥1.0 d.b.h.) indicated an average d.b.h. of 2.0, 3.3, 5.3, and 6.8 inches and average volume of 1377, 2148, 2875, and 3305 ft^3/acre at age 11, 23, 31, and 36 years, respectively. Table 2 illustrates the effect of simulated CTR treatments on stand structure by stand age. The abundance of crop trees declined from 81 to 16 trees per acre, and the number of cut trees required to apply CTR declined with stand age.

Table 3 contains the simulated results for each stand age when the crop trees are released using the logging method detailed above and projected to their optimal economic rotation. Stand A reached its optimal economic rotation at age 71 with a cumulative PNW of $14.10/acre. Stand B reached its optimal economic

Table 3.—Simulated results for crop tree release with logging system by stand at the optimal economic rotation age

Logging System	Stand A	Stand B	Stand C	Stand D
Release age (yrs)	11	23	31	36
Average d.b.h. of cut trees (in)	2.21	4.52	6.79	9.16
Trees cut (trees/ac)	367	218	143	106
Volume cut (ft^3/ac)	353.03	576.44	874.85	1217.74
Mill value ($/ac)	158.67	259.07	393.19	548.60
Logging cost ($/ac)	182.80	299.15	455.06	410.77
PNW[ab] of CTR harvest($/ac)	-15.68	-16.26	-18.34	33.58
Optimal economic rotation (ORA)(yrs)	71	68	76	76
Average d.b.h. at ORA (in)	9.14	9.98	14.73	12.89
Trees cut/acre at ORA	418	285	124	152
Volume cut/acre at ORA (ft^3/ac)	4555.61	3887.89	3986.21	3737.02
Mill value at ORA ($/ac)	2037.44	2042.59	4141.84	3101.87
Logging cost at ORA ($/ac)	1555.19	1322.46	649.24	557.32
PNW of final harvest at ORA[b] ($/ac)	29.78	50.02	177.26	129.14
Cumulative PNW both harvests ($/ac)	14.10	33.76	158.92	162.72

[a]Real discount rate = 4 percent
[b]Discounted to age 0

Table 4.—Simulated results for the unreleased crop trees by stand at the optimal economic rotation age

Logging System	Stand A	Stand B	Stand C	Stand D
Release age (yrs)	0	0	0	0
Average d.b.h. (in)	0	0	0	0
Trees cut (trees/ac)	0	0	0	0
Volume cut (ft^3/ac)	0	0	0	0
Mill value ($/ac)	0	0	0	0
Logging cost ($/ac)	0	0	0	0
PNW[ab] of CTR harvest($/ac)	0	0	0	0
Optimal economic rotation (ORA)(yrs)	86	98	76	66
Average d.b.h. at ORA (in)	9.24	12.73	12.82	12.99
Trees cut/acre at ORA	484	224	197	173
Volume cut/acre at ORA (ft^3/ac)	5178.28	5168.79	4675.71	4227.22
Mill value at ORA ($/ac)	2355.58	3033.52	3080.32	2734.53
Logging cost at ORA ($/ac)	1771.19	773.33	699.94	635.48
PNW of final harvest at ORA[b] ($/ac)	20.04	48.40	120.81	157.70
Cumulative PNW both harvests ($/ac)	20.04	48.40	120.81	157.70

[a]Real discount rate = 4 percent
[b]Discounted to age 0

rotation at age 68 with a cumulative PNW of $33.76/acre. Stand C reached its optimal economic rotation at age 76 with a cumulative PNW of $158.92/acre. Stand D reached its optimal economic rotation at age 76 with a cumulative PNW of $162.72/acre. Table 4 contains results for each stand age grown to its optimal economic rotation without CTR. The untreated stands reached their optimal economic rotation at ages 86, 98, 76, and 66 with cumulative PNWs of $20.04/acre, $48.40/acre, $120.81/acre, and $157.70/acre, respectively. The cumulative PNW results are compared in Figure 1. From age 11 to 23 years, PNWs

Table 5.—Simulated results for crop tree release with logging system by stand at rotation age of 100 years

Logging System	Stand A	Stand B	Stand C	Stand D
Release age (yrs)	11	23	31	36
Average d.b.h. (in)	2.21	4.52	6.79	9.16
Trees cut (trees/ac)	367	218	143	106
Volume cut (ft^3/ac)	353.03	576.44	874.85	1217.74
Mill value ($/ac)	158.67	259.07	393.19	548.60
Logging cost ($/ac)	182.80	299.15	455.06	410.77
PNW[ab] of CTR harvest($/ac)	-15.68	-16.26	-18.34	33.58
Assumed rotation (yrs)	100	100	100	100
Average d.b.h. at 100 yrs (in)	11.12	13.04	17.40	15.72
Trees cut/acre at 100 years	326	199	91	123
Volume cut/acre at 100 years (ft^3/ac)	5629.57	4955.88	4340.25	4858.87
Mill value at 100 years ($/ac)	2798.09	3495.43	5701.92	5267.16
Logging cost at 100 years ($/ac)	1940.02	749.94	570.48	837.53
PNW of final harvest at 100 yrs[ab] ($/ac)	16.34	52.27	97.70	84.33
Cumulative PNW both harvests($/ac)	0.66	36.01	79.36	117.91

[a]Real discount rate = 4 percent
[b]Discounted to age 0

Table 6.—Simulated results for the unreleased crop trees by stand at rotation age 100 years

Logging System	Stand A	Stand B	Stand C	Stand D
Release age (yrs)	0	0	0	0
Average d.b.h. (in)	0	0	0	0
Trees cut (trees/ac)	0	0	0	0
Volume cut (ft^3/ac)	0	0	0	0
Mill value ($/ac)	0	0	0	0
Logging cost ($/ac)	0	0	0	0
PNW[ab] of CTR harvest($/ac)	0	0	0	0
Assumed rotation (yrs)	100	100	100	100
Average d.b.h. at 100 yrs (in)	10.11	13.15	15.10	17.27
Trees cut/acre at 100 years	391	214	160	120
Volume cut/acre at 100 years (ft^3/ac)	5432.11	5352.61	5546.40	5621.23
Mill value at 100 years ($/ac)	2592.60	3223.14	4530.51	5455.80
Logging cost at 100 years ($/ac)	1858.17	815.87	930.85	738.72
PNW of final harvest at 100 yrs[ab] ($/ac)	13.99	45.83	68.53	89.81
Cumulative PNW both harvests($/ac)	13.99	45.83	68.53	89.81

[a]Real discount rate = 4 percent
[b]Discounted to age 0

were slightly greater with no CTR. At age 31 and 36 years, CTR resulted in a greater PNW. Although the results in Figure 1 are discrete points by stand age and the curves are linear between points, the results suggest that CTR would be beneficial starting at about age 25 and continuing to about age 36.

Table 5 displays results of simulated CTR assuming a fixed rotation of 100 years instead of the optimal economic rotations. For comparison, the stands were projected to a 100-year rotation without CTR (Table 6). The cumulative PNWs for the released stands at age 100 were $0.66/acre, $36.01/acre, $79.36/

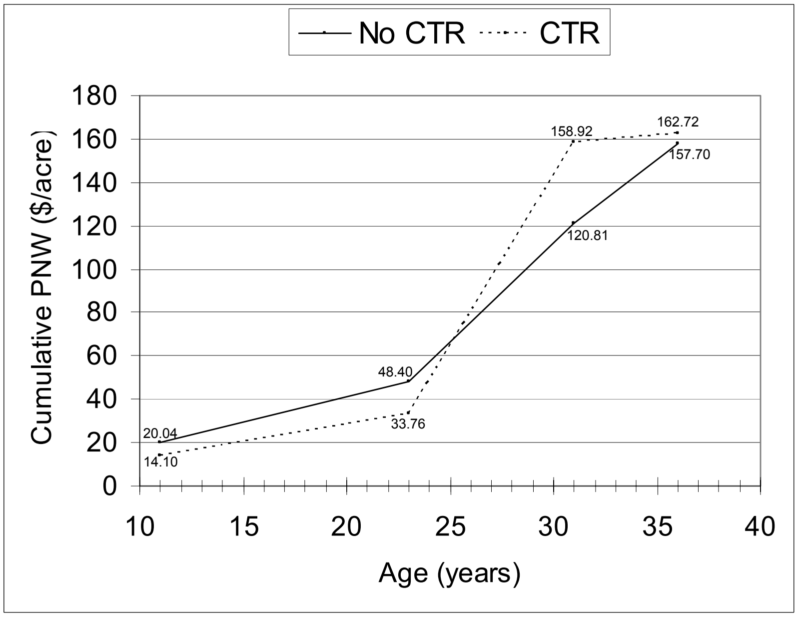

Figure 1.—Cumulative PNW by stand age at the optimal economic rotation age for crop tree released and unreleased stands using logging methods.

Figure 2.—Cumulative PNW by stand age for rotation age 100 of crop tree release and unreleased stands using logging methods.

acre, and $117.91/acre, respectively (Table 5). The cumulative PNWs for the unreleased stand were $13.99/acre, $45.83/acre, $68.53/acre, and $89.81/acre, respectively (Table 6). The cumulative PNWs for the released and unreleased stands are compared in Figure 2. Again, for ages 11 to 23 years, PNW was greater without CTR, and for ages 31 to 36 CTR provided a higher PNW.

Figure 3 illustrates the cumulative PNW curves for CTR using herbicides instead of harvesting, followed by growth to a 100-year rotation. The cumulative PNW differences for ages 11 and 23 were $1.52/acre and $0.25/acre, respectively. The cumulative PNW differences for ages 31 and 36 were $21.65/acre and $9.51/acre, respectively. The curves suggest that for ages 11 through 23, CTR with herbicides provides about the same benefits as not treating the stands. The economic benefit of treating very young stands is limited because the wood products harvested are small diameter and are not yet merchantable, and because the investment period to carry the treatment costs to final harvest is very long. We can also infer that for stands between ages 23 and 34 years, CTR with herbicides is better than no release treatment (Fig. 3).

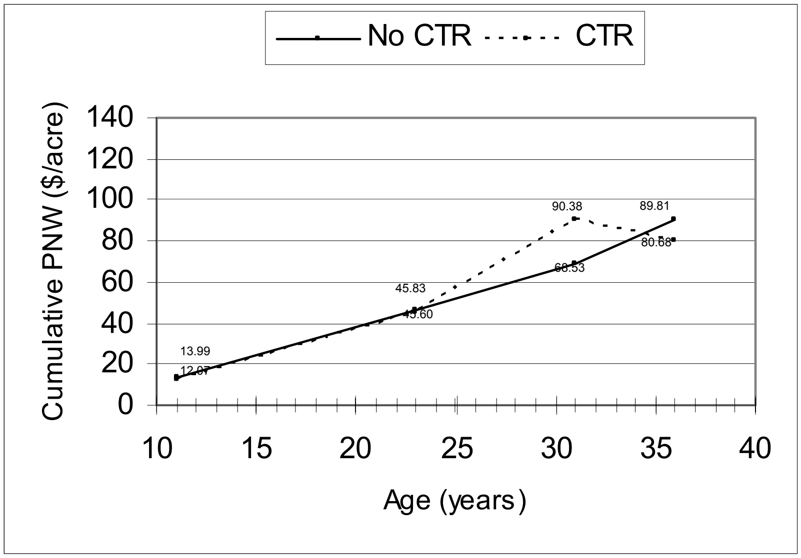

Figure 3.—Cumulative PNW by stand age for rotation age 100 of crop tree release and unreleased stands using hack-and-squirt injection methods.

As tree diameters increase with age, the wood products harvested begin to offset the treatment costs, and the investment period to carry the treatment costs to final harvest is shorter. The herbicide release is better than logging release between ages 25 and 30 (Fig. 4). This outcome is attributable to the fact that the herbicide treatment costs less than the logging method because the logging costs are not being offset by revenue from the harvested wood products. However, for stands age 35 and beyond the herbicide release has a lower PNW than the no-treatment alternative. In older stands, the long-term benefit of CTR is limited because the number of crop trees per acre is greatly reduced compared with younger stands. Moreover, the herbicide release does not yield merchantable products to offset the treatment cost. At stand age of 35 and beyond, it is better to release the stands with logging methods (Figs. 2 and 3). Using a logging method to treat the stand is better in the oldest age class tested here because the cut-trees provided an immediate net revenue (Tables 3 and 5) that offsets the logging costs and provides some profit for the landowner.

CONSIDERATIONS FOR MANAGERS

The results summarized in this paper are unique to the stand structure, site quality, species composition, stand ages, logging technology, herbicide treatment cost, the real discount rate of 4 percent, the simulation model used, and other assumptions made during the simulations. The results show what is possible when an integrated approach is used to evaluate the optimal economic timing of CTR treatments. There can be measurable economic advantages to applying CTR treatments when hardwood stands are young. As stands age, CTR can also be advantageous using logging methods since the trees removed can provide a positive cash flow at treatment time. For some stands, CTR may not provide an economic benefit and the stands should be allowed to grow untreated. Stands with extremely low or extremely high potential value are not good candidates for CTR. For example, stands with few crop trees offer little potential benefit for CTR because there is limited opportunity to affect long-term species composition and stand value. Similarly, stands with abundant crop trees of high value are likely to exhibit favorable long-term species composition without CTR. Finally, the opportunity costs of growing stands beyond the optimal economic rotation can be substantial (LeDoux 2004), although managers may wish to grow stands beyond the optimal economic rotation age for other objectives.

Figure 4.—Precommercial CTR using herbicides in this 21-yr-old mixed hardwood stand provides the highest PNW compared to the no-treatment or the commercial logging options. As stand age approaches 35 years, CTR using the commercial logging option provides the highest PNW.

LITERATURE CITED

Kochenderfer, J.D.; Zedaker, S.M.; Johnson, J.E.; Smith, D.W.; Miller, G.W. 2001. **Herbicide hardwood crop tree release in central West Virginia.** Northern Journal of Applied Forestry. 18(2): 46-54.

Lamson, N.I.; Smith, H.C.; Perkey, A.W.; Brock, S.M. 1990. **Crown release increases growth of crop trees.** Res. Pap. NE-635. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 8 p.

LeDoux, C.B. 2000. **Matching skidder size to wood harvested to increase hardwood fiber availability: A case study.** Forest Products Journal. 50(10): 86-90.

LeDoux, C.B. 2007. **Impact of alternative harvesting technologies on thinning entry and optimal rotation age for Eastern hardwoods.** In: Buckley, D.S.; Clatterbuck, W.K., eds. Proceedings, 15th Central Hardwoods forest conference; 2006 February 27-March 1; Knoxville, TN. e-Gen. Tech. Rep. SRS-101. U.S. Department of Agriculture, Forest Service, Southern Research Station: 122-128.

LeDoux, C.B. 1986. **MANAGE: A computer program to estimate costs and benefits associated with Eastern hardwood management.** Gen. Tech. Rep. NE-112. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern forest Experiment Station. 7 p.

LeDoux, C.B. 2004. **Estimating the capital recovery costs of managing for old growth forests.** In: Proceedings of the 6th eastern old growth forest conference; 2004 Sept. 23-26; Moultonborough, NH. Durham, NH: New Hampshire Cooperative Extension: 31.

Miller, G.W.; Kochenderfer, J.N.; Knibbs, J.H.; Baumgras, J.E. 2001. **Vegetative conditions and management options in even-age stands on the Monongahela National Forest.** In: Barras, Stanley J., ed. Proceedings: National silvicultural workshop; 1999 October 5-7; Kalispell, MT. Proceedings RMRS-P-19. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 40-47.

Ohio Agricultural Statistics Service. 2007. **Ohio timber price report.** Reynoldsburg, OH: Ohio Department of Agriculture, Agricultural Statistics Service. 2 p.

Pennsylvania State University. 2007. **Pennsylvania woodlands timber market report.** University Park, PA: Pennsylvania State University. October-December. 4 p.

Perkey, A.W.; Wilkins, B.L.; Smith, H.C. 1994. **Crop tree management in eastern hardwoods.** NA-TP-19-93. Morgantown, WV: U.S. Department of Agriculture, Forest Service, Northeastern Area State and Private Forestry. 108 p.

Perkey, A.W.; Wilkins, B.L. 2001. **Crop tree field guide: Selecting and managing crop trees in the central Appalachians.** NA-TP-10-01. Morgantown, WV: U.S. Department of Agriculture, Forest Service, Northeastern Area State and Private Forestry. 97 p.

Tennessee Division of Forestry. 2007. **Tennessee forest products bulletin.** Nashville, TN. October-December. 13 p.

West Virginia University Division of Forestry. 2007. **Timber Market Report.** Morgantown, WV. 5th Quarter. 2 p.