

# **PRODUCTION ECONOMICS OF HARVESTING YOUNG HARDWOOD STANDS IN CENTRAL APPALACHIA**

**Yaoliang Li**, Graduate Research Assistant  
**Jingxin Wang**, Assistant Professor  
West Virginia University  
Division of Forestry  
Morgantown, WV 26506

**Gary Miller**, Research Forester  
USDA Forest Service  
Northeastern Research Station  
Morgantown, WV 26505

**Joe McNeel**, Director  
West Virginia University  
Division of Forestry  
Morgantown, WV 26506

## **ABSTRACT**

Three harvesting systems of chainsaw/cable skidder, fell-buncher/grapple skidder, and harvester/forwarder were simulated in harvesting three hardwood stands of 30 to 50 years old in central Appalachia. Stands were generated by using a stand generator and harvesting prescriptions included clearcut, shelterwood cut, selective cut, diameter limit cut, and crop tree release cut. The interactions among stands, harvest prescriptions, and harvesting systems were evaluated in terms of production/cost, and traffic intensity. Results should be useful for planners, loggers, and foresters to efficiently manage and utilize small diameter materials in the region.

## **INTRODUCTION**

Harvesting young stands of high densities and with small diameter trees is becoming a concern to forest products companies, loggers, and landowners in order to reduce fuel loading and improve residual stand health and timber utilization. However, such a harvesting usually is more labor intensive and not cost-effective due to the small piece size processed and the unmerchantable harvested products. LeVan-Green and Livingston (2001) reported that average costs for thinning on small diameter trees is approximately \$70/ton while traditional markets for thinned material can only pay approximately \$25/ton for energy and \$35/ton for chips.

Production and economic feasibility of thinning or partial cutting have been reported by many researchers in different regions. Miller (1993) studied the financial aspects of partial cutting practices in uneven-aged central Appalachian hardwood stands. He reported that single-tree selection is good for regeneration of a desirable, commercial tolerant species. Miller and Baumgras (1994) evaluated four silvicultural practices (single-tree selection, group selection, two-age management, and even-aged management) for managing eastern hardwoods in terms of economic feasibility. They indicated that two-age management gave the highest production rate for the sawtimber only option and single-tree selection had the lowest production rate.

Research on the interactions of stand conditions, machine attributes, and harvest prescriptions especially for harvesting young hardwood stands appears to be lacking in the region. Such a lack of information has resulted in management decisions being based on either experience or very limited field tests. The objectives of this study are to (1) generate three Appalachian hardwood stands of 30, 40, and 50 years old, respectively, (2) perform harvesting and extraction operations on these three stands under different harvesting prescriptions by using a computer simulation model, and (3) statistically evaluate the production/cost effectiveness of the alternative harvesting systems.

## MATERIAL AND METHODS

### Stands

Three natural young hardwood stands of 30, 40, and 50 years old in central Appalachia were generated using a 3D stand generator (Wang et al. 2002). Each stand was 1.0 acre in size and with random distribution. Stand densities were 531, 374, and 290 trees per acre 30, 40, and 50 years old stands, respectively. DBH averaged 5.2, 6.6, and 8.3 inches while the average total height varied from 69.6, to 54.7, and to 55.7 ft. for these three stands, respectively. Major species included sugar maple, American basswood, sweet birch, black cherry, yellow poplar, and black cherry.

### Harvesting Systems

Two commonly used harvesting systems of chainsaw (CS)/cable skidder (CB) and feller-buncher (FB)/grapple skidder (GP) in central Appalachia together with harvester (HV)/forwarder (FW) system were examined in the simulation study. Functions that were modeled for each machine were as follows (Wang and Greene 1999, Long 2003):

Chainsaw: walk to tree, acquiring, cutting, and topping/delimiting;

Cable skidder: travel empty, choke, travel loaded, and unchoke;

Feller-buncher: drive to tree, cut tree, drive to dump, and dump;

Grapple skidder: travel empty, grapple, travel loaded, and release;

Harvester: move, boom extend/retreat, cut, swing boom, processing, and dumping;

Forwarder: move to load, load, travel loaded, and unload.

Felling simulations were performed on a 1.0-acre plot, which was replicated 36 times and gave a total of 36 acres of each stand for extraction simulations. The felling machine was first located at one end of the plot, then it moved parallel to a swath of trees. When the end of the swath was reached, the machine turned back and started another nearest swath until all trees selected to be cut were felled (Wang and Greene 1999). For the extraction simulation, landing was assumed to be in the middle grid at the bottom of the logging site and the main skidding roads were located in the middle of the logging site for cable and grapple skidders. Forwarder followed the trail of the harvester.

Four travel intensity categories were used to monitor the traffic of skidders and forwarder (Carruth and Brown 1996):

TI1 – Trees on the plot have been felled.

TI2 – Trees that stood on the plot have been removed and no other traffic has passed through the plot.

TI3 – Trees that stood on the plot have been removed and trees outside the plot have been skidded through the plot. Passes with a loaded machine are between 3 and 10.

TI4 – More than 10 loaded machine passes have been made through the plot.

### Harvesting Prescriptions

Five different harvesting methods were examined including clearcut (CC), shelterwood cut (SW), crop tree release cut (CT), diameter limit cut (DL), and selective cut (SC). The smaller trees were removed in favor of desirable shade-tolerant trees for the shelterwood cut while the selective cut removed dominant trees and stimulated the growth of the trees of lower crown classes. The diameter limit cut removed all trees larger than 12 inches DBH. Taking stumpage price into consideration, crop tree release cut removed 80% of the basal area and released valuable species such as black cherry, red oak, walnut, and hard maple selective cut removed 30% of basal area.

### Data Analysis

A three-factor, full factorial design (3x3x5) was implemented for the experiment. There were a total of 45 treatment combinations. Each combination was replicated three times for a total of 135 felling simulation experiments. Another 135 extraction simulations were conducted based on felling results. Data were analyzed using analysis of variance (ANOVA).

## RESULTS

### Felling Operations

Average DBH of felled trees varied from 6 to 17 inches while average total height was between 50 and 81 feet (Table 1). Volume per felled tree changed from 4.5 to 35.3 ft<sup>3</sup>. Volume per acre removed was between 713.6 and 1997.8 ft<sup>3</sup>. Distance traveled between harvested trees differed significantly among

stands, and between harvester and chainsaw or feller-buncher. Harvester always presented the least ground travel distance and was about half the distance by a feller-buncher or a logger with chainsaw. This was due to the harvester can cut several trees at one machine stop.

Cut time per tree differed significantly among stands ( $F = 88.62$ ;  $df = 2,134$ ;  $P = 0.0001$ ) and felling machines ( $F = 260.36$ ;  $df = 2,134$ ;  $P = 0.0001$ ). It was not significantly different among clearcut, shelterwood cut, and crop tree release cut because these three harvest methods removed trees of similar sizes. Felling cycle time differed significantly among machines ( $F = 2470.86$ ;  $df = 2,134$ ;  $P = 0.0001$ ) but it was not significantly different among stands.

Felling productivity was significantly different among stands ( $F = 5828.57$ ;  $df = 2,134$ ;  $P = 0.0001$ ) and among felling machines ( $F = 9135.05$ ;  $df = 2,134$ ;  $P = 0.0001$ ) with  $595.16 \text{ ft}^3/\text{PMH}$  for clearcut and  $386.57 \text{ ft}^3/\text{PMH}$  for shelterwood cut. Hourly felling production increased with the DBH of felled trees. Harvester was more sensitive to DBH than feller-buncher and chainsaw. Feller-buncher felling consistently presented the higher productivity compared to chainsaw and harvester felling.

### Extraction Operations

Bunch size averaged 22.6, 51.8, and  $112.6 \text{ ft}^3$  for 30-year-old, 40-year-old, and 50-year-old stands, respectively (Table 2). Turn payload varied from 86.1 of grapple skidder, to 109.5 of cable skidder, and to  $411.2 \text{ ft}^3$  of forwarder. Average extraction distance (AED) varied among stands, harvest, and machine. Forwarder resulted in a longer forwarding distance of 1041 feet due to its larger payload. Average skidding distances with cable and grapple skidders were similar and ranged from 700 to 805 feet.

Average skidding time was 16.0 and 12.9 minutes for cable and grapple skidders, respectively. Forwarding cycle time averaged 38.9 minutes. Extraction cycle time differed significantly among extraction machines ( $F = 875.09$ ;  $df = 2,134$ ;  $P = 0.0001$ ). TI2 differed significantly among stands ( $F = 40.20$ ;  $df = 2,134$ ;  $P = 0.0001$ ) and extraction machines ( $F = 466.85$ ;  $df = 2,134$ ;  $P = 0.0001$ ). Both TI3 and TI4 were also significantly different among stands and among extraction machines. Extraction productivity averaged 253.4, 589.4, and  $803.1 \text{ ft}^3$  per PMH for cable skidder, grapple skidder, and forwarder, respectively. It differed significantly among stands ( $F = 1005.25$ ;  $df = 2,134$ ;  $P = 0.0001$ ) and extraction machines ( $F = 8366.77$ ;  $df = 2,134$ ;  $P = 0.0001$ ).

### Cost and System Analysis

The harvesting systems were balanced and compared based on their cost and production rate. One chainsaw and one cable skidder were used for the chainsaw/cable skidder system, one feller-buncher and two grapple skidders were used for the feller-buncher/grapple skidder system, and two harvesters and one forwarder were used for the harvester/forwarder system. Cost estimates of logging machines were calculated by using the machine rate method (Miyata 1980). Hourly cost of a representative chainsaw was  $\$29.0/\text{PMH}$  in the region with a mechanical availability of 50% (Long 2003). Feller-buncher has an hourly cost of  $\$94.6$ . Hourly costs were estimated at  $\$48.6$  and  $\$44.3$  for cable and grapple skidders. Operating harvester and forwarder could cost  $\$99.5$  and  $\$72.6$  per hour, respectively.

The productivity of chainsaw/cable skidder (CS/CB) system was  $164.6 \text{ ft}^3/\text{PMH}$  with the unit cost of  $\$0.38/\text{ft}^3$  in clearcut while system productivity decreased to  $86.7 \text{ ft}^3/\text{PMH}$  with the unit cost of  $\$0.73/\text{ft}^3$  in shelterwood cut. Compared with the manual system (CS/CB), the two mechanized systems of feller-buncher/grapple skidder (FB/GP) and harvester/forwarder (HV/FW) were much more productive. They required higher initial investment and maintenance fees. However, their relatively higher production somewhat offset the higher costs. System productivity increased while the unit cost decreased from chainsaw/cable skidder system to harvester/forwarder, and to feller-buncher/grapple skidder system. System production rate and unit cost also varied with harvest methods.

## CONCLUSIONS

Felling production and cost were affected by tree size removed, harvesting prescriptions, and machines. Compared with chainsaw and feller-buncher, harvester was more sensitive to individual tree size. Feller-buncher was the more cost-effective and productive felling machine. Clearcutting always presented the highest productivity while the shelterwood cut was the lowest productive method. The crop tree release cut removed the smaller trees, which had almost the same silvicultural effects as shelterwood cut but without sacrificing the stumpage price. The productivity of crop tree release cut was similar to diameter limit cut and selective cut.

Extraction was mainly affected by payload size and average extraction distance. Due to its higher payload, forwarder was the most productive machine with an hourly production of 803.1 ft<sup>3</sup>/PMH, which was about three times higher than that of a cable skidder. The lower productivity of cable skidder was partly caused by the time consumed for choking, which accounted for about 25 percent of the total cycle time of the cable skidder skidding. TI3 and TI4 was one of the most concerns because of the higher damage level to the soil. Because of the lower payload and more machine passes, the TI3 and TI4 level for both cable skidder and grapple skidder was up to 40% across the site in clearcut and still more than 20% with the other three methods (SW, CT, DL). However, TI3 and TI4 level was consistently less than 20% across the site with forwarder no matter what harvest method was used.

Chainsaw/cable skidder system was the least productive system in comparisons with harvester/forwarder and feller-buncher/grapple skidder systems. The feller-buncher/grapple skidder system was the most cost-effective in harvesting young hardwood stands under the simulated harvesting prescriptions. The simulated results in this study can be used as guidance for managing young hardwood stands in central Appalachian region. It is also helpful for evaluating different harvest methods and harvesting prescriptions. Future work should include the operating cost for marking trees, which is not negligible for crop tree release cut and selective cut. Residual tree damage is also a major concern of landowners and forest managers. This should also be cooperated into the simulation later.

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Table 1. Means and significance levels of felling simulation variables<sup>1</sup>.

	Stand			Machine					Harvest		
	30	40	50	CS	FB	HV	CC	SW	CT	DL	SC
DBH removed (in.)	7.79c		12.37a	10.41a	10.34b	9.12c		6.10e	6.18d	13.95b	16.87a
Avg. total height (ft.)	57.80c	64.46b	67.25a	64.36a	64.29a	60.86b	53.36c	51.80d	51.37e	78.25b	81.06a
Volume per felled tree (ft <sup>3</sup> )	4.57c	10.46b	22.30a	12.68a	12.66a	11.99b	5.90c	3.99e	4.64d	12.39b	35.28a
Volume removed (ft <sup>3</sup> /acre)	713.65c	1157.60b	2124.01a	1313.99b	1313.28b	1367.99a	1997.82a	1280.90c	1478.64b	956.79d	944.62d
Distance traveled per harvested tree (ft.)	15.04c	17.31b	19.08a	21.38a	21.37a	8.68b	8.76c	9.00c	9.50c	21.74b	36.72a
Time per tree (productive min)	1.76c	2.19b	3.02a	3.26a	1.12c	2.59b	0.91c	0.95c	1.03c	2.99b	5.73a
Cycle time (min)	4.27b	4.12b	4.80a	3.26b	1.49c	8.43a	3.87c	3.93c	4.48b	4.60b	5.09a
Productivity (ft <sup>3</sup> /PMH)	253.39c	433.07b	716.62a	234.07c	795.57a	373.44b	595.16a	386.57d	434.39c	497.00b	425.36c

<sup>1</sup>Means containing the same letter in a row are not significantly different at the 5 percent level with Duncan's Multiple-Range Test.

Table 2. Means and significance levels of extraction simulation variables.

	Stand			Machine				Harvest			
	30	40	50	CD	FW	CC	SW	CT	DL	SC	
Turn payload (ft <sup>3</sup> )	165.18c	196.13b	245.47a	109.53b	86.05c	411.19a	197.67c	185.21c	194.83c	226.02a	207.57b
Avg. extraction distance (ft.)	848.67a	865.41a	786.58b	753.77b	805.86a	1041.04a	650.04d	755.65c	653.06d	1018.95b	1090.07a
Bunch size (ft <sup>3</sup> /bn)	22.63c	51.84b	112.59a	38.77c	76.07a	72.22a	29.48c	19.97d	23.28d	62.91b	176.13a
Cycle time (min)	23.33a	22.82ab	21.55b	15.99b	12.87c	38.93a	23.02b	19.77c	20.12c	23.53b	26.40a
TI1	58.33a	54.06b	52.94b	48.11b	39.18c	78.05a	44.14e	46.63d	51.36c	61.15b	76.28a
TI2	27.74a	23.41b	19.55c	26.67b	35.72a	8.31c	27.95a	29.11a	25.95a	19.52b	15.30c
TI3	13.20c	20.70b	23.02a	21.56b	24.44a	10.92c	27.86a	22.03b	20.23b	16.95c	7.81d
TI4	0.73c	1.83b	4.49a	3.67a	0.66c	2.73b	4.05a	2.27b	2.46b	2.38b	0.61c
Productivity (ft <sup>3</sup> /PMH)	444.81c	566.69b	634.46a	253.36c	589.42b	803.08a	561.62b	488.67d	527.02c	592.01a	573.79b

<sup>1</sup>Means containing the same letter in a column are not significantly different at the 5 percent level with Duncan's Multiple-Range Test.