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Recovery of Residue Tops in Selectively Cut Northern Hardwood Stands

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Tests the feasibility and economics of compacting hardwood tops with a prototype shearing and bunching device prior to skidding. Presents productivity levels and costs associated with compacting, skidding, and chipping hardwood tops.

KEY WORDS: Logging residue, chipping, tree damage, productivity, cost.

RECOVERY OF RESIDUE TOPS IN SELECTIVELY CUT NORTHERN HARDWOOD STANDS

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A declining land base, an increasing demand for forest products, plus energy shortages have all contributed to an increased incentive to better utilize forest residues. Forest residues include tops, limbs, cull trees, and cull logs, as well as other unused wood not directly attributed to logging operations such as that from trees that are insect-infested, diseased, wind-blown, or fire-damaged.

It is estimated that slightly more than 200 million dry tons of wood can be recovered annually from these forest residue categories on harvested areas in the eastern United States (Mattson *et al.* 1978). Regionally, 63 percent of these residues are in the South and 37 percent in the North, and generically, 68 percent are hardwoods. With current practices and equipment, chipping is the most feasible technique for converting forest residue into a usable form. Skidding entire tops with limbs intact is one possible approach to topwood recovery. However, in selectively cut stands, roots and boles of residual trees may be damaged excessively (Dye 1972, Steinhilb and Dye 1973). Damage may be especially severe if wood is recovered during spring and early summer when the bark is loose. Chipping tops with large crowns is difficult because they do not feed well into the chipper.

Forest Service scientists developed the concept of mechanically compacting large hardwood tops into a form more suitable for grapple skidding (fig. 1). The experimental topwood processing device to compact the tops is a small, highly maneuverable, hydraulically actuated shear mounted on a knuckle boom of a carrier vehicle. The specially designed mounting mechanism between the shear and boom permits the operator to rotate the shear assembly to almost any orientation. This high maneuverability makes it possible to sever large protruding limbs and then align them with the butt of the main stem of the top. Once all large limbs are severed and aligned, the compacted top is skidded to a woods landing for chipping.

The experimental topwood shearing device was designed to sever and bunch limbs up to 12 inches in diameter. The carrier vehicle was a Gafner series mini-skidder.[1] To allow for fast and efficient operation, we modified the hydraulic control system to combine seven machine functions into two "joystick" controls plus one foot pedal. The shear was attached to the rear-mounted knuckle boom by a rotatable coupling mechanism. The carrier vehicle was selected not because of its superior suitability but rather because of its availability.[2]

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[1]*Mention of trade names does not constitute endorsement of the products by the USDA Forest Service.*

[2]*Memorandum of Understanding between Gafner Machine, Inc., and North Central Forest Experiment Station, U.S. Department of Agriculture, Forest Service—April 30, 1976.*

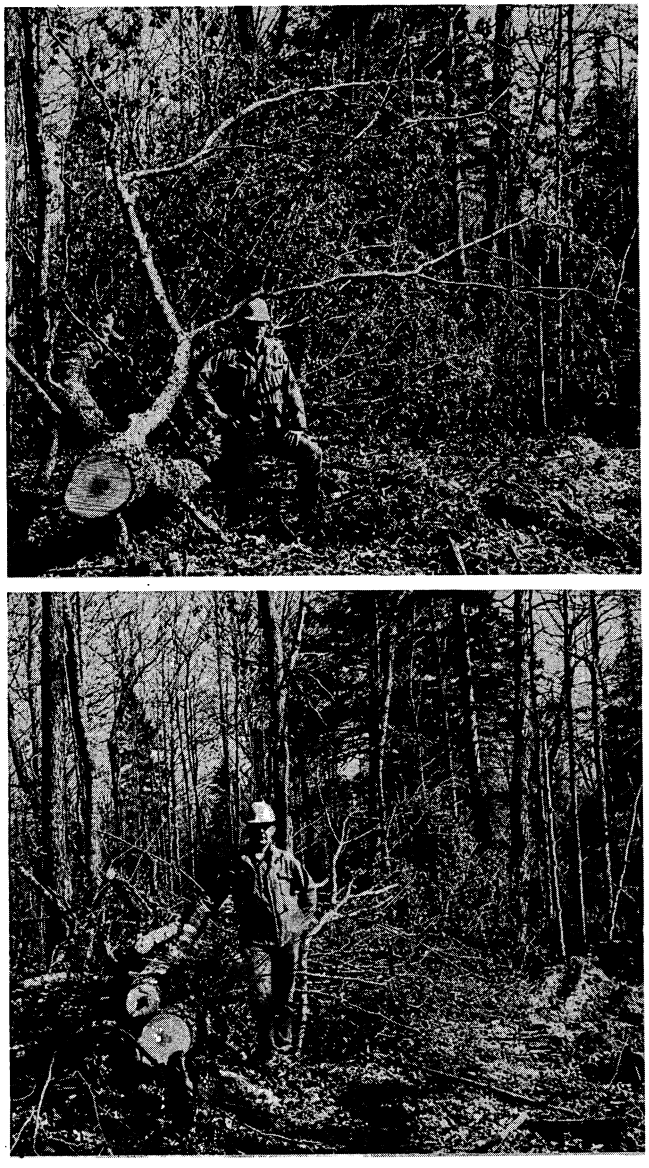

Figure 1.—*In-woods preparation of hardwood saw-timber tops for harvesting (top) Typical hardwood saw log top (bottom) Compacted top.*

THE STUDY AREA

The 21-acre study area was located on Michigan Technological University property at the Ford Forestry Center, L'Anse, Michigan. Preharvest inventory of this northern hardwood stand indicated 7,000 board feet (Net Scribner) of saw logs and 6 cords of pulpwood per acre. The soil, classified as Allouez, was a well-drained, coarse gravelly loam. The tract was on level terrain and was traversed by an all-weather road. Previous selective logging in 1938 and 1967 had removed most of the cull trees often found in northern hardwood stands. Sugar maple and American elm constituted the major species with minor volumes of basswood, yellow birch, red maple, and hemlock totaling 149 trees and 116 square feet of basal area per acre before harvesting (figs. 2, 3).

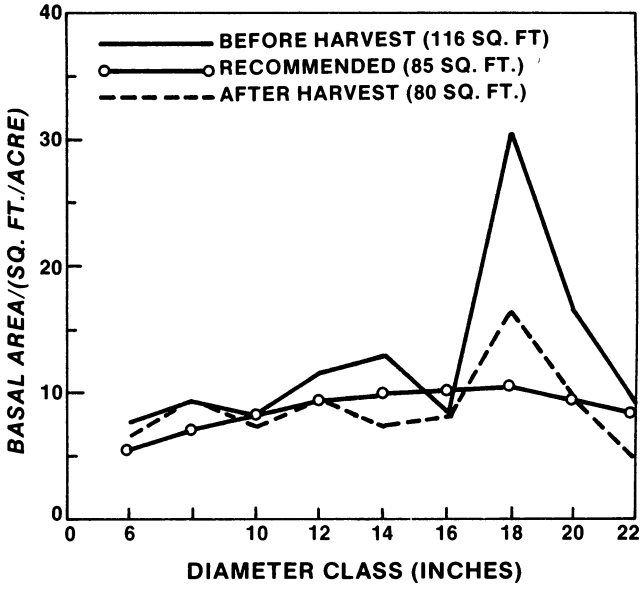

Figure 2.—*Topwood study--trees per acre by diameter class (1977).*

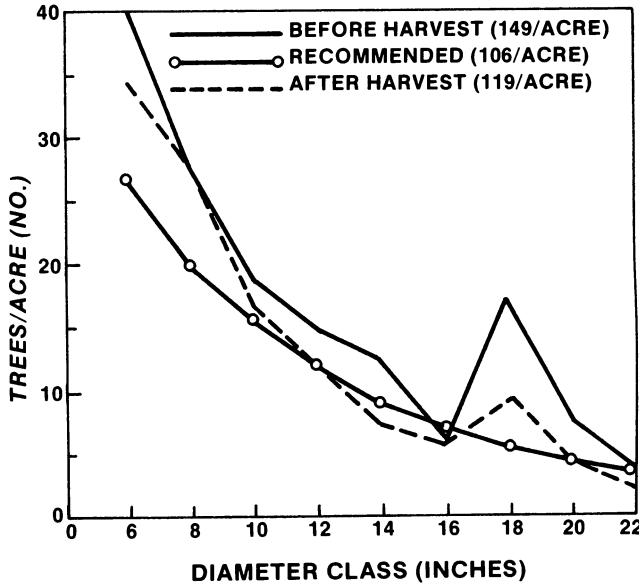

Figure 3.—*Topwood study--basal area per acre by diameter class (1977).*

In 1977, 1,800 board feet of saw logs (Net Scribner) and 5.1 tons (2 cords) of pulpwood per acre were selectively harvested. Most of the pulpwood volume came from the upper stem portions of saw log trees. Utilization of upper stem wood, which varies considerably from one logging job to another, depends largely on the availability of a pulpwood market and on the degree of utilization required by the timber sale contract. On this particular site initial pulpwood recovery from tops was above normal.

Fifty-two percent of the initial harvested saw log volume was sugar maple, 38 percent American elm, 4 percent basswood, and the remaining 6 percent made up of yellow birch, red maple, and hemlock. Basal area was reduced from 116 square feet to 80 square feet per acre in trees 5 inches d.b.h. and larger. A total of 304 trees were marked making an average of 14.5 trees per acre. Sixty-seven trees (22 percent) were less than 11 inches d.b.h. The initial harvest was a conventional short log system except that pulpwood-sized trees were skidded tree length. The logging contractor was not aware that topwood harvesting would follow the logging operation.

METHODS

The principal equipment used in the topwood harvesting recovery trials were the prototype USDA Forest Service shearing device, a Clark Ranger 667 GS Grapple Skidder, and a Morbark 22-inch XL Chiparvestor Chipper (fig. 4).

Postlogging damage to residual trees was assessed following the initial conventional selective saw log harvest on seven 1/5-acre study plots. All felling and skidding damage from conventional saw log removal was identified and recorded. After topwood harvesting, all additional damage was identified and recorded on the same seven plots. Each damaged tree was photographed so future rot progression due to logging damage could be evaluated.

Immediately after felling the trees, the following data were collected: species, diameter (d.b.h.), total height, crown width and length, and butt diameter of the top outside bark. Cubic foot volume of tops to a 1.5-inch minimum diameter outside bark was also determined on sample trees by calipering the midpoints outside bark of sections ranging from 1 to 8 feet in length (figs. 5-7). These measured tops were chipped and weighed separately, so cubic foot/weight relations could be developed. All sample tops were kept separate from the unmeasured tops.

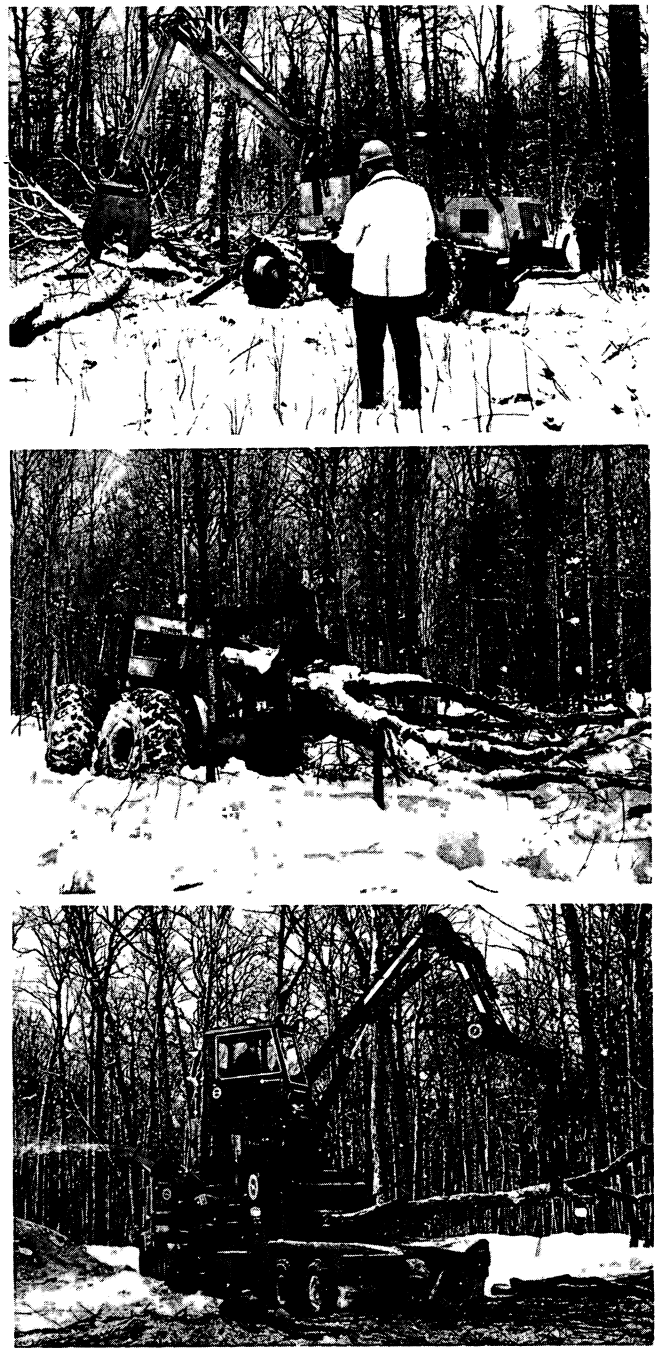

Figure 4.—*Field trials with mechanized topwood recovery: Compacting of residue hardwood top (top); Grapple skidding of processed top (center); and Conventional chipping of processed topwood (bottom).*

Prior to skidding, the topwood harvester sheared and bunched only limbs from the larger crowns. Small

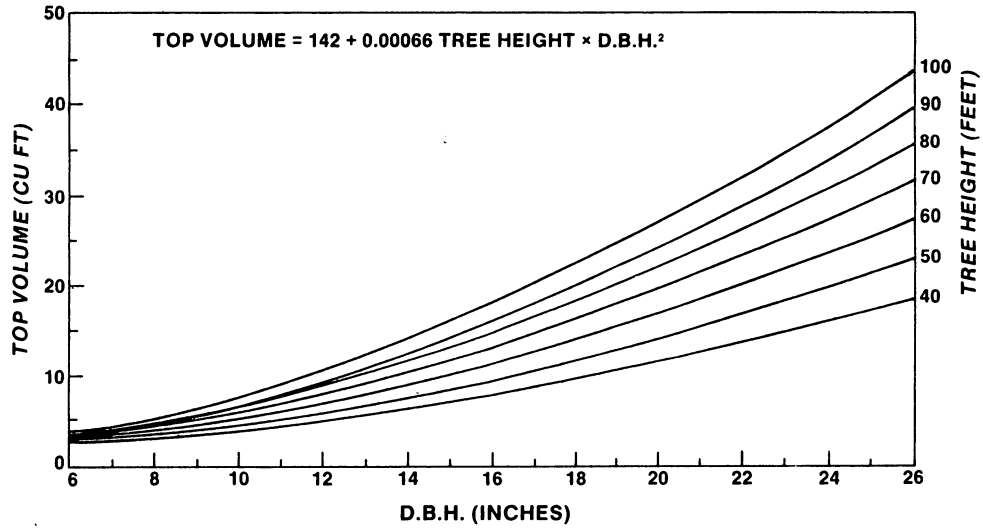

Figure 5.—*Topwood volume by diameter class and height.*

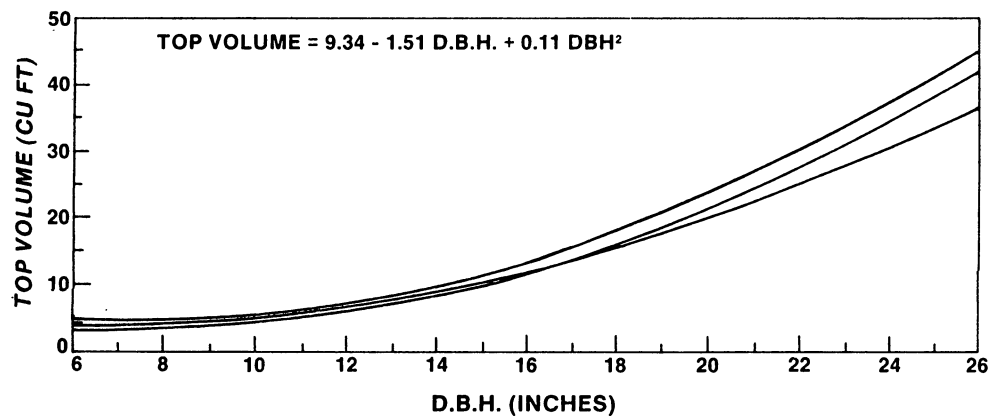

Figure 6.—*Topwood volume by diameter class (95 percent confidence level).*

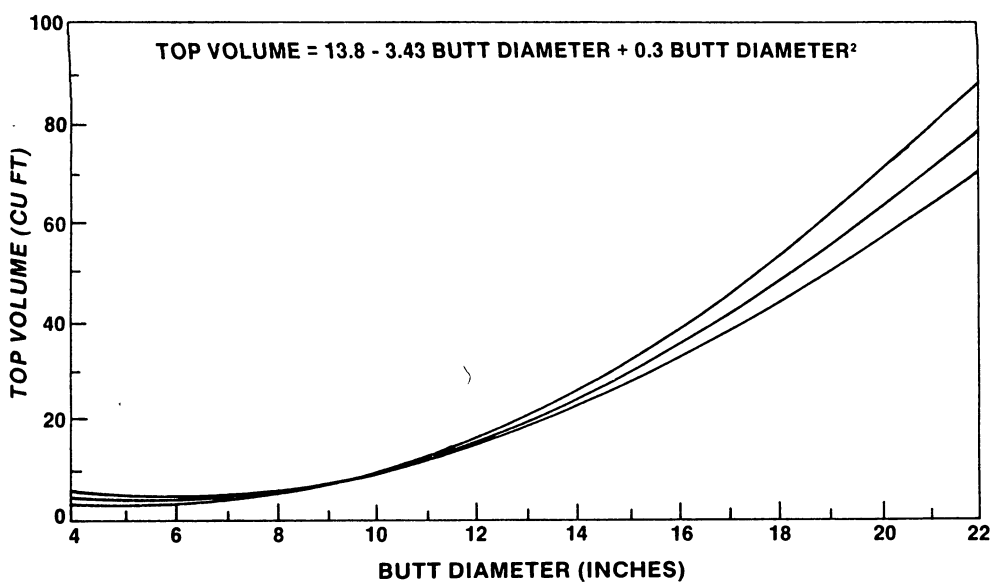

Figure 7.—*Topwood volume by butt diameter of top (95 percent confidence level).*

tops with no large, protruding limbs were not processed with the topwood shear. The tops were then skidded to the roadside.

A chain saw operator was stationed at the landing site to sever any remaining limbs or stubs that hindered chipping. The chipper had a grapple with large teeth welded to the outside. This enabled the operator to split limb forks apart by placing the closed grapple between them and then opening the grapple. Tops were then fed into the chipper. Chips were blown into piles and later hauled by self-loading vans. Twenty tons of chips could be loaded in approximately 20 minutes. The vans were weighed to determine chip weight (green weight).

Time and motion studies were performed on each key element of the topwood recovery operation including vehicle travel between tops. Fuel consumption, number of cuts per top, and diameter of severed limbs were also tallied. Performance of the Clark Ranger 667 GS Grapple Skidder and Morbark 22-inch XL Chiparvestor were also time studied to determine productivity and operating costs.

RESULTS AND DISCUSSION

Of a total of 220 chipped tops, 137 were sampled for volume/weight relations (green weight). The average top was 19.0 cubic feet, 65.3 lbs/ft^3, and 0.62 tons (table 1). The 83 unmeasured tops were also weighed which permitted the calculation of an estimated cubic foot volume by dividing by the sample weight of 65.3 lbs/ft^3. This calculated to 21.4 ft^3 and 0.70 tons/top for the 83 unmeasured tops. The combined average for all 220 tops was 19.9 ft^3 and 0.65 tons/top. The total weight on 21 acres amounted to 285,700 lbs or 6.8 tons/acre.

If the 5.1 tons/acre of pulpwood initially harvested during conventional logging had actually been recovered with the tops, an additional 0.35 tons/top would have been realized and increased the top weight to 1 ton/top. This is comparable to earlier topwood recovery studies.[3] The per-acre yield on the study area would have increased from 6.8 tons to 11.9 tons/acre. A chip sample analysis indicated a moisture content of approximately 40 percent (green basis).

Table 1.—*Topwood recovery weights and volumes*

	Number of tops	Total volume	Total weight	Average volume/top	Average weight/top
		Cu ft	*Lbs*	*Cu ft*	*Tons*
Measured tops chipped	137	2,597,4	169,500	18.96	0.62
Unmeasured tops chipped	83	1,780.6	116,200	[1]21.45	0.70
Total	220	4,378.0	285.700	19.90	0.65

[1]The measured top weight per cubic foot (65.3 lbs.) was used to calculate the unmeasured top volume (1,400 lbs/top ÷ 65.3 lbs/cu ft = 21.4 cu ft/top).

The prototype topwood harvester was used to cut and bunch 115 tops. In addition, the operator arbitrarily decided that 40 tops were too small to process. The measurements of the trees were as follows:

	Processed	Skipped
Total tops (number)	115	40
D.b.h. of trees (inches)	18.7	13.2
Height of trees (feet)	79	68
Top width (feet)	27	17
Top length (feet)	37	37
D.o.b. of butt end (inches)	13.4	9.1

Processing of the 115 tops ranged from 1 to 7 cuts/top. Diameters of cut limbs ranged from 2 to 11 inches with an average of 6.5 inches (fig. 8).

Topwood harvester delays were classified into three groups: (1) unavoidable—those associated with production, such as operator decision-making prior to processing, cutting saplings that impeded topwood processing, and repositioning or moving limbs to improve accessibility to complete a top; (2) mechanical—those associated with production using a prototype machine such as problems with the controls or shear blades, oil leaks from loose or poorly protected fittings, etc., would normally be eliminated in the production machine; and (3) avoidable—those related to the prime mover, such as lifting and lowering stabilizer pads and climbing in and out of the two seats required to operate this machine. Lunch and breaks were not included. The average processing time per top was as follows:

	Processing time/top (Minutes)
Time per top (without delays)	4.1
Unavoidable delays	.2
Mechanical delays	.8
Avoidable delays	.6
Total	5.7

It should again be noted that the prime mover was not selected because it was an ideal machine but rather because of its availability.

[3]*United States Department of Agriculture, 1976. Unpublished data from prototype shearing development project. U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station, Forestry Sciences Laboratory, Houghton, Michigan.*

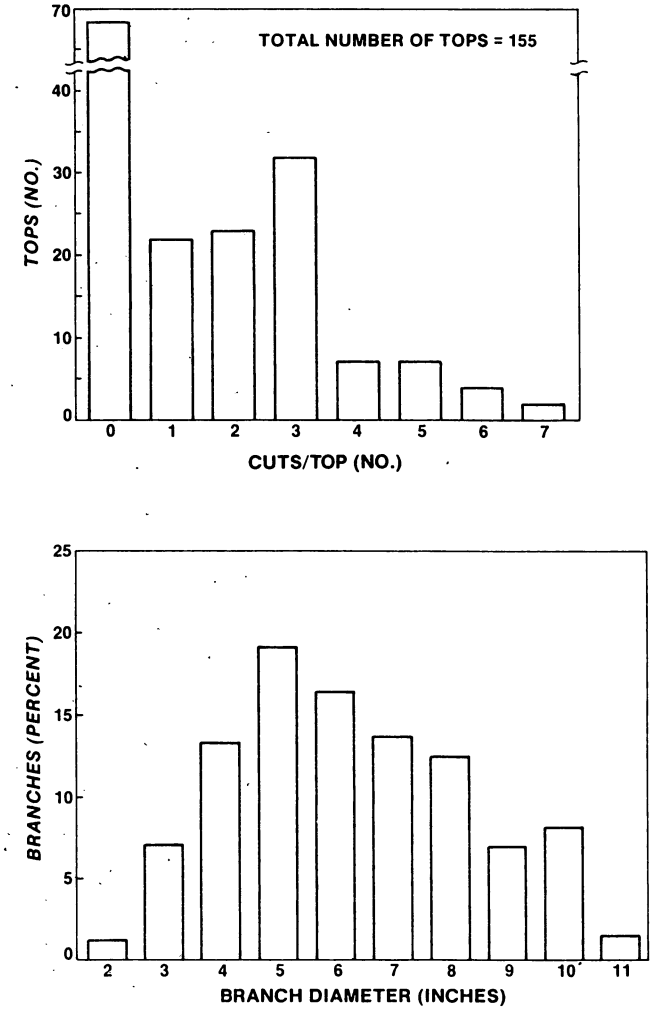

Figure 8.—*Summary of number (top) and size (bottom) of limbs severed.*

Because of the high degree of utilization in the conventional harvest and resulting small tops, topwood processor productivity was low:

	Topwood processor productivity	
	(Tops/hr)	(Green tons/hr)
Without delays	14.6	10.2
With unavoidable delays	11.7	8.2
With all delays	10.5	7.4

Previous residue studies (Mattson and Carpenter 1976) showed that in similar stands in which product utilization was not as high, nearly half of the weight of harvested trees was left in the woods.

Two skidding methods were tried: (1) direct skidding of both processed and unprocessed tops from the woods to the landing, and (2) "shuttle" skidding in which larger loads of tops were piled at intermediate locations along the service road before skidding the remaining distance to the landing. The purpose of "shuttle" skidding was to simulate the productivity and costs for a two skidder system. Average round trip skidding distance was 1,700 feet—828 feet in the woods and 872 feet on skidding road. Skidder productivity was as follows:

	Direct skidding	Shuttle skidding[4]
Skidder utilization (percent)	75	81
Tops/load	1.2	1.6
Tons/load (green weight)	0.84	1.12
Tops/hour (without delay)[5]	8.9	21.1
Tops/hour (with delays)	6.7	17.1
Tons/hour (without delay, green weight)	6.3	14.8
Tons/hour (with delays, green weight)	4.8	12.0

The study was expected to run from August through December of 1977; however, due to delays it was necessary to extend it further into the winter. The resulting snow depths of 30 inches or more adversely affected operation efficiency. It reduced performance because the skidder had difficulty maintaining traction. Also many tops were nearly completely covered with snow and some were frozen to the ground and needed to be broken free. An increase in productivity of at least 10 to 20 percent could likely have been realized with better conditions.

As shown in the following tabulation, chipper utilization was low:

	Direct skidding	Shuttle skidding
	(Green tons/hr)	
Chipper utilization (percent)	25	32
Without delays[6]	17.5	25.7
With all delays	4.3	8.3

[4]*Based on one skidder operating 2.6 days in the woods and 1 day on the road to the landing.*

[5]*Work elements were (1) reach, position, and grapple; (2) lift and set; and (3) travel. All other elements were considered as delay time.*

[6]*Work elements were (1) reach, position, and grapple; (2) lift, swing and feed; (3) chip; (4) blow onto the pile on the ground. All others were considered as delay time.*

The main reason for the low chipper productivity was the limited skidder could not feed it to capacity. Chipper productivity was greater for shuttle skidding than for direct skidding because of the larger skidder loads. This allowed the chipper operator to increase the size of grapple loads when feeding the chipper, thus reducing the delay time waiting for tops:

Equipment	Without delays	With delays
	(Minutes/ton)	
Topwood processor	5.9	8.1
SHUTTLE SKIDDING METHOD		
Skidder	4.1	5.0
Chipper	2.3	7.2
DIRECT SKIDDING METHOD		
Skidder	9.5	12.5
Chipper	3.4	14.0

Because the experimental processing head of the topwood harvester was unable to sever all limbs close to the main stem, some of the remaining limb stubs had to be cut before the main stem could be fed into the chipper. Although this was not time consuming, it resulted in added chipper delay. The chain saw cost at the landing was $0.30 per green ton. An improved topwood processor head should be capable of removing limbs closer to the main stem and preclude the need to trim short stubs, thus eliminating a man at the landing. In comparing costs, the skidder operation had the highest cost per ton and per top, amounting to $3.85 (shuttle skidding) and $9.05 (direct skidding) per green ton (table 2). Total production cost, excluding transportation, ranged between about $10.00 to $16.50 per green ton depending on skidding method used. The reader is cautioned that these costs should be tempered by the fact that they are the result of a single case study with an experimental machine.

RESIDUAL TREE DAMAGE

Damage to the residual trees was as follows:

Damage category	Damage trees	
	(No./acre)	(Percent)
CONVENTIONAL LOGGING		
Felling	4.3	4
Skidding	12.9	11
Total	17.2	15
TOPWOOD SKIDDING		
Additional trees damaged	5.0	4
Additional damage to previously damaged trees	3.6	3
Total	8.6	7

Table 2.—*Summary of cost for harvesting hardwood saw log tops*

(In 1980 dollars)

Equipment	Production cost[1]			
	Cost per top		Cost per green ton	
	Shuttle skidding	Direct skidding	Shuttle skidding	Direct skidding
Topwood processor	2.37	2.37	3.39	3.39
Skidder	2.70	6.41	3.85	9.05
Chipper	1.75	2.57	2.50	3.67
Chain saw	0.21	0.21	0.30	0.30
Total	7.03	11.56	10.04	16.41

[1]At 100 percent utilization (without delay).

The 22 percent total damage compares closely with a topwood skidding study conducted in 1957 in which 21 percent of the trees 5 inches d.b.h. and larger sustained injury (Hooker 1957).

Hesterberg (1957) determined that wound width and wound surface area are the best indicators of the severity of logging damage. He found that 50 percent of the wounds 150 square inches or greater show decay at the end of 10 years. Stem wounds exposed for more than 20 years had a 50 percent frequency of decay when more than 60 square inches of sapwood was exposed, and 80 to 100 percent frequency of decay when 130 square inches or more were exposed. He further concluded that 92 percent of the decay could be explained by the original wound width. More than 50 percent of the stem wounds show decay within 10 years when logging scars are more than 7 inches wide. For a 20-year-old injury, 50 percent show decay when they are 4 to 7 inches wide and 100 percent show decay when the wound is 7 inches wide or wider. Because few of the injuries exceeded 50 square inches surface area, we arbitrarily divided the injuries as either medium (26 square inches or more of cambium or wood exposed) or light (less than 26 square inches of cambium or wood exposed). Eighty-three percent of the bole injuries due to conventional skidding were classified as "light" and 17 percent as "medium." Topwood skidding resulted in 75 percent "light" and 25 percent "medium" injuries. Measurable root injuries occurred only during the conventional logging phase of the harvest which was conducted during the summer. Topwood harvesting was conducted on snow-covered ground, thus eliminating additional root damage. Of those roots damaged by conventional skidding, 90 percent were "light" and 10 percent were "medium."

The injury level recorded in this study appears to be acceptable because none of the damage was severe. The majority of the wounds exposed less than 50 square inches of sapwood. Based on Hesterberg's work, we expect most of the smaller wounds to heal over without causing significant amounts of rot. Also, some of the more seriously damaged trees will probably be harvested before major decay occurs.

The logging contractor's awareness of the importance of minimizing damage can contribute significantly to maintaining quality residual trees.

CONCLUSIONS AND RECOMMENDATIONS

Because of low yields and the necessity of a highly mechanized system, the feasibility of any topwood recovery system will depend heavily on economic and market conditions. This unique field trial evaluated the potential and identified various problems, many of which could be eliminated. This approach to recovering topwood is only one of several possible approaches.

Of the 155 tops in the topwood harvester plot, 115 were compacted by the topwood harvester and 40 were skidded as is, because of an arbitrary decision that they could be skidded intact without causing severe residual stand damage. After observing the residual stand damage, it appears that these figures could likely have been reversed—40 compacted and 115 skipped. In some instances it was easier to skid uncut tops because the short, crooked pieces of the cut tops slipped out of the grapple when the load shifted. A skidder with a constant pressure grapple should lessen this problem.

A major consideration is how to increase the size of skidder payloads. Although two methods were tried in this study, neither was satisfactory. A choker skidder may prove more productive than a grapple, primarily because several tops could be collected in the woods along with large limbs, thus eliminating double handling. At the landing the tops and limbs could be bucked into highest value products with the small branches chipped and the logs set aside for transport to the sawmill.

This was a one-of-a-kind study with no chance to improve operator skill. Skilled operators obviously would increase productivity and overall efficiency of any logging operation. The handling and chipping of saw log topwood is more difficult than conventional whole-tree chipping of pulpwood-sized trees and consequently requires skilled operators.

Sawtimber operations typically leave large tops from which pulpwood sticks have not been removed. This added top length facilitates feeding into the chipper because it gives the chipper feed rolls something to engage to get the top started. It may be desirable to leave the pulpwood sticks in other types of logging, too, if topwood is to be salvaged.

For this study, a chain saw operator was stationed at the chipper at all times to make any necessary cuts on the tops so they could be chipped. Because this operator was utilized only 13 percent of his time, it might have been more efficient to have the chipper operator also do the chain saw work. Another alternative would be to replace the chipper grapple with a grapple that utilizes a hydraulically actuated chain saw built within the grapple and controlled by the chipper operator. An improved topwood processor should be capable of severing limbs closer to the main stem thereby eliminating the need to do any chain sawing.

Another approach is to use a topwood harvester outfitted with bunk skidding capabilities. This basic type of machine is already available and is typically equipped with a loader and inverted grapple on the carrier bed. If the loader were adapted with a topwood processing head, a single vehicle could reduce tops as well as load and skid the processed tops.

This study has demonstrated the potential of recovering tops through compaction without greatly damaging the residual stand. Harvesting during the spring or early summer, when bark is slipping, would most certainly increase damage. Stands with many pole-sized trees (5 to 9 inches d.b.h.) would probably make harvesting more difficult and also result in increased damage to the residuals.

This study has documented the topwood volumes that might be recovered from selectively cut northern hardwoods. If low quality trees were harvested along with the tops, volumes per acre would increase and the economic picture would be even more attractive. As the demand for whole-tree chips increases and the value of chips for fuel becomes more attractive, topwood harvesting will be of greater importance. It is in the interest of the forest industry that good sound production and cost figures are available for harvesting logging residues.

The results of this unique approach establish baseline data for one method of recovering tops and

limbs. We know of no other attempt to recover topwood by this method, and at this time we neither recommend nor disapprove of the approach. Certainly other approaches exist and these should be researched and documented. Hopefully, after investigating several approaches, an economically feasible method will result.

These data may be considered as lower limits of what could be accomplished. As more is learned about organizing topwood harvesting jobs and as operators become more experienced, productivity and cost ratios should improve.

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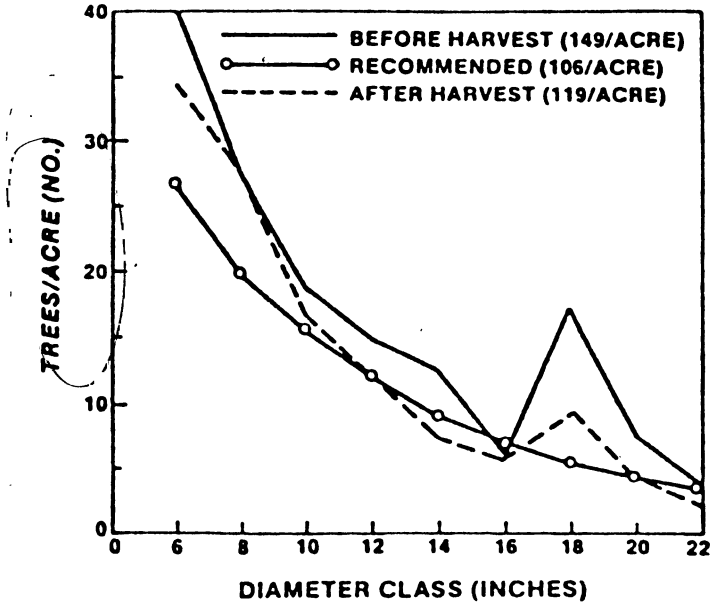

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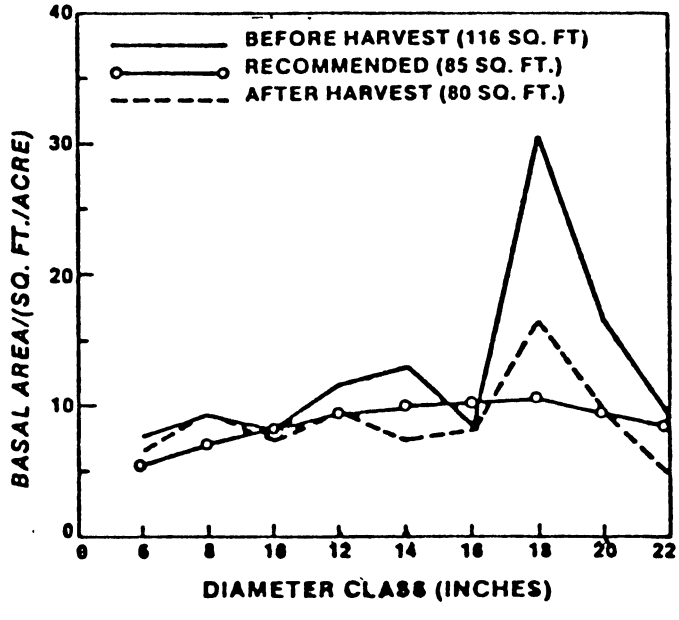

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