Development of a Puller-Buncher for Harvesting Southern Pines With Taproot Attached

Peter Koch S. J. Coughran

Abstract

A harvester-buncher that mounts on the front of a wheeled skidder has been developed to pull entire pine trees from the ground like carrots. Two elements are central to its design. The first is a scissors-type grip equipped with a pair of stout horizontal knife blades that close at the groundline and bite several inches into the stem from opposite sides of the tree. The second element in the design is a clamshell-hinged tubular shear 22 inches in diameter and sharpened on the lower edge. With the scissors grip as an anchor, the shear is forced vertically into the ground to a depth of about 11 inches, severing lateral roots all around the tree. At this depth, broad steps on opposite sides of the tubular shear strike the ground and prevent further penetration; application of additional force on the shear causes the steps to bear against the ground and the grip to rise about 9 inches, thereby jacking the tree free of the ground with taproot attached. Finally, the complete tree is lifted into the air and bunched for skidding. With this equipment southern pines up to 13 inches in diameter were harvested and bunched at sustained rates of 1 to 2 trees per minute. For 16-year-old loblolly pines on dry loamy-clay soil, force to sever lateral roots (including force to penetrate soil) did not exceed 75,000 pounds; lifting force did not exceed 65,000 pounds. The stump-taproot portion of loblolly pines harvested near Cedartown, Georgia, averaged 18 percent of the green weight of merchantable stems from 2-inch stump height to about a 3-inch top diameter outside bark. In slash pine and longleaf pine plantations row-thinned near Panama City, Florida, the stump-taproot averaged 22 percent of merchantable stem weight to a 2-inch top outside bark. On loamy-clay soils

The authors are Chief Wood Scientist, USDA Forest Service, So. Forest Expt. Sta., Pineville, La., and Director, Product Development, Rome Industries, Cedartown, Ga. This paper was presented at Session 26 – Timber Production & Harvesting – of the 28th Annual Meeting of the Forest Products Research Society, June 27, 1974, in Chicago, Ill. It was received for publication in October 1974.

considerable dirt adhered to the taproots, but slash and longleaf pines pulled from sandy soils did not dull knives excessively when chipped entire. Several thousand slash and longleaf pines with taproots attached were processed through a drum debarker, chipped, and converted into kraft paper without unusual problems immediately detectable.

DURING THE YEARS 1963 TO 1972 the senior author wrote a book on the utilization of southern pine. Sections of this book reported his research on shearing and cleaving (Koch 1972, pp. 797-808); the shearing research was also reported in the *Forest Products*

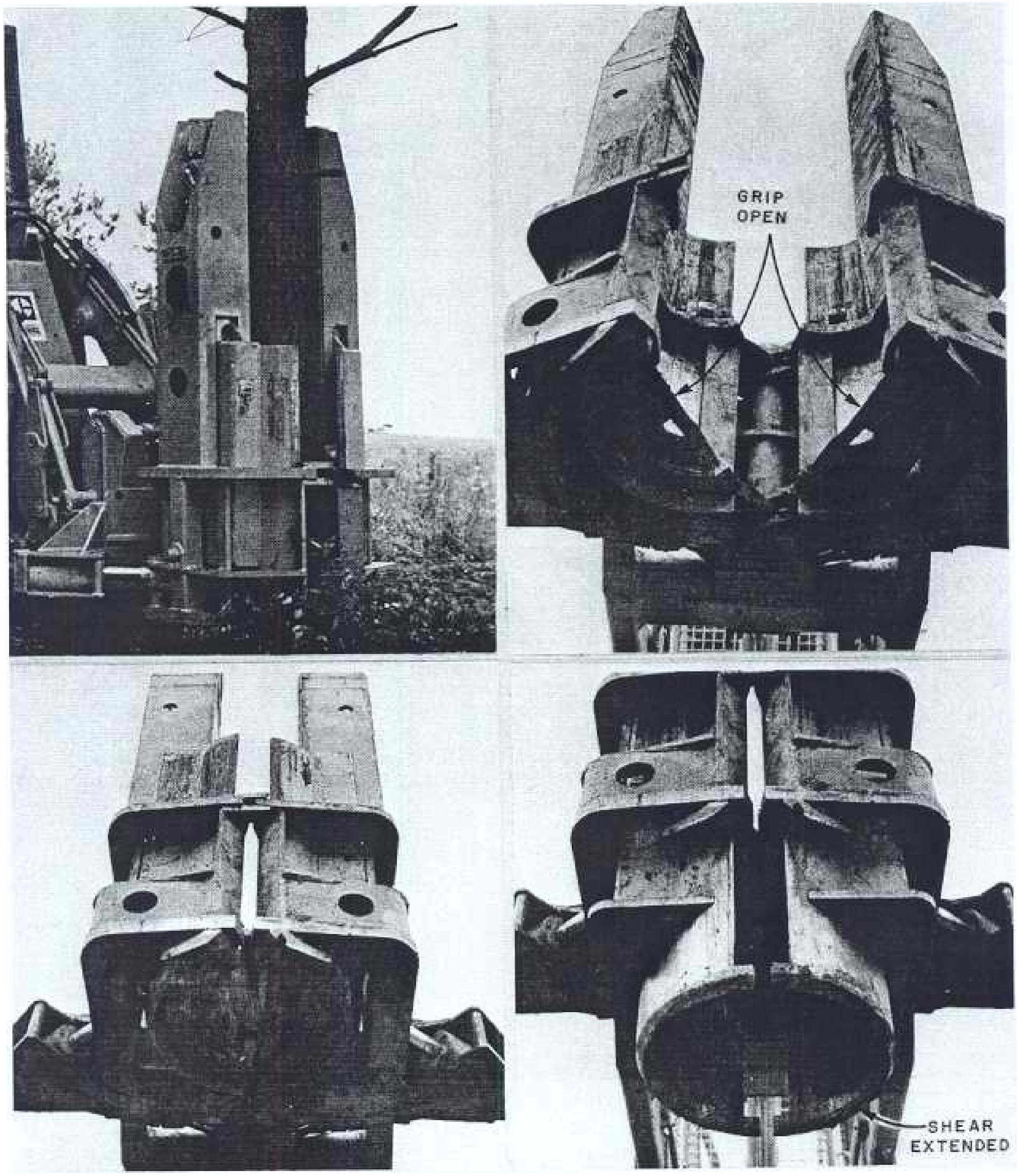

Figure 1. — Experimental commercial lateral root shear. (Top left) Rome TX-1600 harvester mounted on a conventional 4-wheel-drive articulated loader, with hinged grip closed on tree to be harvested. (Top right) View of grip in open position with shear retracted. (Bottom left) Grip closed; in operation the knives grip the tree stem at ground level. (Bottom right) Grip closed and tubular shear fully extended 20 inches. Steps that bear against soil surfaces during last 9 inches of extension are visible on opposite outer sides of the shear tube. Each side of the tube is independently driven through its 20-inch stroke by a 6-inch hydraulic cylinder housed in the vertical column.

Figure 2. — Complete loblolly pine tree, with taproot attached, pulled from the soil like a carrot after lateral roots have been severed. The tree measures 10 inches DBH; the taproot is 20 inches in diameter 6 inches below ground line and about 6 feet long from stump height. Considerable dirt is visible on the taproot.

Journal (Koch 1971). The data on shearing and cleavage underlie the development here reported.

An entire chapter of the book (pp. 537-574) dealt with the characteristics of southern pine roots and their uses. A stimulating bit of information reviewed during the writing of this chapter was the work by Sproull and his associates. They advanced the idea of complete-tree utilization–from roots to twigs–and provided data indicating that the stump and roots of 17- to 41-year-old southern pines were a substantial fraction of the complete tree and that these portions could be pulped to yield kraft paper of good quality (Sproull et al. 1957).

Howard (1973) confirmed Sproull's estimate of slash pine (*Pinus elliottii* Engelm. *var. elliottii*) taproot and stump volume as about 20 percent of merchantable bole weight (dry basis). Moreover, her data on chemical constituents of the stump-root system explained why the kraft process can produce satisfactory rootwood pulps. Manwiller (1972) showed that southern pine rootwood has tracheids of greater length and larger diameter, but with thinner walls, than stemwood sampled 18 to 24 inches above ground level.

In addition to the foregoing information, a key stimulus was provided the senior author during redrafting, for inclusion in the 1972 book, of Ashe's (1915) sketches of loblolly pine (*Pinus taeda* L.) roots and Wahlenberg's (1946, p. 220) drawings, after Liefeld, of longleaf pine (*Pinus palustris* Mill.) roots. Photographs of pitch pine (*Pinus rigida* Mill.) and shortleaf pine (*Pinus echinata* Mill.) root systems by McQuilkin (1935), and observations of slash pine roots during the course of Howard's (1973) excavations, reinforced the picture of southern pine trees as typically having a shallow system of lateral roots and a thick, tapered, deeply penetrating taproot. The literature indicated that this root form develops over much of the southern pine range, where soils are well-drained and relatively rock-free.

The last steps in evolvement of the concept occurred at the 1972 Seventh World Forestry Congress in Buenos Aires, Argentina, where the senior author

Figure 3. After they are harvested, trees with taproots attached are bunched in conventional fashion to be forwarded by a grapple skidder. Some dirt is loosened as the tree is dropped to the ground.

spent a day composing an article on whole-tree utilization of southern pine (Koch 1973), and the following day listening to descriptions of Scandinavian trials of equipment to uproot stumps after trees were felled. It was on the long flight back to Louisiana that all of the facts suddenly came together with the realization that if the shallow lateral roots of southern pines were first severed adjacent to the taproot, then the complete tree, with taproot attached, could be lifted from the soil like a carrot, thereby adding 20 percent to the dry weight of wood harvested.

Prototype Trial

To develop this idea, the Southern Forest Experiment Station placed a purchase order for exploratory tests with Rome Industries, Cedartown, Georgia. In these tests, a makeshift, clamshell-hinged, tubular shear was fabricated to sever lateral roots. Lifting force was provided by a stem-gripping mechanism attached to a long-stroke hydraulic cylinder anchored to the upper framework of a standard Rome shear. The entire apparatus was carried by a JD 544A wheeled prime mover. In September 1973 the prototype was tested at Cedartown, where it lifted 15-year-old, plantation-grown pines from dry, hard, loamy-clay soil (Koch 1974a,b).

The concept worked as planned. During the first stage of harvesting, the tubular shear was driven into the ground to sever the laterals. Then the stem and taproot were lifted through the shear. The hole left by the root was small and quickly caved in as the felling machine traveled about the area.

From this experiment it was estimated that forces required to drive the tubular shear into dry clay soil might exceed 100,000 pounds for a tree 12 inches in diameter at breast height (DBH). Maximum taproot diameter, occurring a few inches below ground level, was typically 1.5 to 2 times DBH. In these young trees, harvestable length of the taproot was 3 to 5 feet, measured from groundline.

Design of Experimental Commercial Model

The purchase order to Rome Industries called not only for prototype trials but for a conceptual machine design based on the data. In satisfaction of this order, the junior author provided the Southern Forest Experiment Station with drawings of an experimental commercial machine that appeared to be workable.

Rome Industries decided that the concept appeared promising and that the company would finance design refinement and manufacture of the experimental commercial model. The resulting hardware, mounted on a Caterpillar 920 wheeled prime mover, was ready for initial test June 13, 1974, in Cedartown (Fig. 1). Through quick-hitch mechanisms the harvester can be mounted on most prime movers.

Two elements are central to the design. The first is a scissors-type grip achieved with a pair of stout horizontal knife blades that close at groundline and bite several inches into the stem from opposite sides (Fig. 1, bottom left).

With this grip as an anchor, the second element in the design, a clamshell-hinged, 22-inch-diameter, 3/4-inch thick, tubular shear sharpened on the lower edge, is forced vertically into the ground to a depth of 11 inches, thereby severing lateral roots all around the tree. At this point broad steps on opposite sides of the shear (Fig. 1, bottom right) strike the ground and prevent further penetration. An additional stroke of the hydraulic cylinder raises the grips 9 inches, while the steps remain stationary, pressed against the soil surface. The effect is to jack the stem and break it free of the ground. Finally the complete tree is lifted into the air (Fig. 2) and bunched for skidding (Fig. 3). Since actuation of the shear takes only a few seconds, a tree can be harvested and bunched in less than a minute.

Field Trials of the Experimental Commercial Model

Cedartown, Georgia

After minor modifications, the unit was refitted to a JD 544B prime mover. Two series of trials were then run at Cedartown in a loblolly pine plantation 16 years old. Soils were loamy clays. More than 1,000 trees, 5 to 10 inches in DBH, were harvested and bunched at a rate well over 60 per hour.

The first trials were started on June 25, 1974, after a rain had left the soil moist. The second series was begun July 13, when the soil was extremely dry.

Both force to shear laterals and force to lift trees after lateral severance were greater in dry soil than in moist (Table 1). In no case, however, did severance force (including force to penetrate soil) exceed 75,000 pounds, and lifting force never exceeded 65,000 pounds. Forces were estimated from oil pressure in the two 6-inch cylinders activating the two halves of the lateral root shear. When operating at maximum pressure (3,000 psi), each of the two 6-inch actuating cylinders can exert about 90,000 pounds, for a total of 180,000 pounds of severance or lifting force. It would therefore seem that the cylinders are of more than adequate size for trees of the diameters lifted.

In these Cedartown trials soil tended to cling to stumps and taproots (Fig. 2). A considerable proportion of this dirt was shaken free when the tree was bunched (Fig. 3), but some remained. Holes left after trees were harvested varied from inconspicuous indentations to cavities 22 inches across and a foot deep (Fig. 4). Skidding partially filled most of the holes.

Georgia Kraft Company Evaluation of Trees Uprooted in Cedartown

Ten loblolly pines uprooted June 25, 1974, at the Cedartown site were analyzed 14 days later for weight and dimensions. The work was done under the supervision of Bernard Davis, of the Wood and Woodlands Division of the Georgia Kraft Company at Rome, Georgia. He provided all the data described under this heading.

Table 1. — FORCES TO SHEAR LATERALS AND LIFT TREES AFTER SEVERANCE OF LATERALS, IN MOIST AND DRY LOAMY CLAY, CEDARTOWN, GEORGIA.

Soil condition and tree DBH (inches)	Force to shear laterals	Force to lift tree after severance of laterals
	lb.	lb.
Moist soil		
5	21,000	21,000
7	30,000	30,000
7	30,000	36,000
7 (double-tree)	36,000	35,000
8	24,000	24,000
8	27,000	26,000
9	33,000	33,000
9	36,000	36,000
10	30,000	30,000
10	42,000	40,000
	36,000	30,000
Dry soil		
5	27,000	25,000
5	30,000	30,000
6	52,000	50,000
7	30,000	30,000
7 (double-tree)	36,000	30,000
8	30,000	42,000
8	45,000	54,000
8	54,000	Tree broke
8 (double-tree)	66,000	48,000
12	47,000	54,000
14	75,000	65,000

Figure 4. — Hole 22 inches in diameter and a foot deep after a 12-inch tree was pulled from central Georgia loamy clay. On sandy sites holes are less conspicuous.

Procedure was as follows:

- Merchantable stems were chainsawn from the stump-taproot at a stump height 2 inches above groundline, and from the top at a stem diameter of 3 to 3-1/2 inches outside bark.
- Lengths of merchantable stems, stump-taproots, and tops were measured.
- Merchantable stems were bucked into 7-foot-long pulpsticks, and weighed as a group.
- Stump-taproots were weighed as a group with adhering dirt included.
- Stump-taproots were washed with a high-pressure water hose, allowed to dry overnight, and reweighed.
- Weights of tops and limbs were not measured, but were estimated from previously collected data for trees of similar dimensions.

The ten trees, which ranged in DBH from 6 to 8 inches, had average dimensions as follows:

	Average	Standard deviation
Diameter, inches		
Ground level	10.80	1.48
Stump level	8.88	1.09
Breast height	7.08	0.62
Length, feet		
Entire tree above 2-inch-high stump	44.17	3.27
Merchantable stem	31.33	2.86
Top	12.84	1.80
Stump-taproot	4.87	1.10

Trees of 8-inch DBH had greater merchantable length (35 feet) than those 6 to 6.5 inches DBH (30 feet). Stump-taproot length increased with tree diameter; trees with DBH in the range from 7 to 8 inches had stump-taproot lengths of about 5 feet. Trees 6 to 6.5 inches in DBH had taproots about 3.5 feet long.

Stump-level diameters were about 1.8 inches greater than diameters at breast height, and groundline diameters were about 3.7 inches greater than at breast height.

Weight analysis of the trees follows:

Portion	Green weight
Merchantable pulpwood in stem	
Stump-taproot, including dirt	
Stump-taproot after washing	
Dirt washed from stump-taproot	
Limbs and tops (estimated)	

From these data on loblolly pines from the Cedartown site, it appears that harvesting of the stump-taproot would increase fiber utilization 18 percent (i.e., from 2,990 to 3,550 pounds) over conventional harvesting methods, but only 13 percent (i.e., from 3,648 to 4,208 pounds) over total-tree chipping of above-ground parts.

No evaluation of harvesting costs was attempted. It was recognized that dirt adhering to the stump-taproot is a serious obstacle.

Figure 5. — Heavy, nearly cylindrical, taproot on longleaf pine pulled from sandy clay soil near Panama City, Florida. The tree is about 9 inches in diameter at breast height, and the taproot measures nearly 22 inches at its largest diameter.

International Paper Company Field Trials

After the initial trials at Cedartown, the harvesting attachment was moved to slash pine and longleaf pine plantations a few miles north of Panama City, Florida. Here A. Wimpenny, Jr., and his associates of the International Paper Company conducted trials over a period of more than 10 operating days in August 1974.

During the trials, several thousand trees were harvested in a corridor thinning operation in which every third row was removed. Because of the sandy soil, dirt adherence was considerably less than at Cedartown; moreover, the stump-taproot comprised a substantially greater fraction of tree weight (Fig. 5). For essentially all of the trees harvested, stump-taproots averaged 22 percent of the weight of the merchantable stems to a 2-inch top (green-weight basis).

With the paper company's operators, the equipment extracted and bunched 1.9 trees per minute in stands up to 10 inches in diameter; in stands with trees to 13 inches in diameter, the production rate was 1.1 trees per minute. These values are averages for all shifts.

Some of the trees (enough to yield one van load of chips) were processed entire, with taproots attached, on a mobile whole-tree chipper; knives dulled somewhat more rapidly than usual. Also, root swell caused some difficulty in feeding.

Subsequently stump-taproots were chipped separately from stemwood in this machine, and the chips were evaluated separately. In these trials neither stems nor roots were debarked prior to chipping. Data collected (Table 2) showed that stump-taproot chips had a lower moisture content (MC), a lower specific gravity, and a lower bulk density than stem chips. They also were larger and thicker, and had higher ash and silica contents, than stem chips.

The balance of the trees were skidded, bunched for loading (Fig. 6), and transported to the mill. Because of the knob-like structure of the taproots, somewhat less payload could be transported per truck than with conventional stems. Also, the long taproots on some stems would have caused the truck to exceed the maximum permissible overall length of 75 feet; such stems had to be reduced in length before loading.

To avoid undue conveyor problems at the mill, stub laterals on the taproots were closely trimmed in the field. Stems, with taproots attached, were then sent through the mill's drum debarker and chipped in normal fashion. When the chips were pulped in mixture with regular chips, no immediate problems were detected. It was observed that the cambium layer was removed in the barking drum, and the roots emerged as clean and free of dirt as could be expected for knotty wood of irregular shape.

Prospects for Regionwide Application

On August 29, 1974, after conclusion of the Panama City tests, Rome Industries and the Southern Forest Experiment Station staged a field-day explanation and demonstration at Cedartown. About 80 people attended. Most were forest managers and wood procurement men, and a few were papermakers.

As a result of this demonstration, additional field trials throughout the South were scheduled for late

Table 2. — COMPARISON OF CHIPS FROM UNDEBARKED STUMP-TAPROOTS (2-INCH STUMP HEIGHT) WITH CHIPS FROM UNDEBARKED STEMS, BOTH PRODUCED BY A WHOLE TREE CHIPPER OF INTERNATIONAL PAPER COMPANY, AT PANAMA CITY, FLORIDA.

Item	Stem	Stump-taproot
MC, percent of green weight	47.4	44.8
Specific gravity, basis of green volume and ovendry weight	.50	.43
Bulk density, pounds of ovendry (OD) wood per cubic foot of chips		
Loose	10.6	9.6
Packed	13.2	11.9
Ash content, percent of OD weight	.30	1.24
Silica content, percent of OD weight	.03	.41
Chip size as determined by Williams' chip classification, percent retained on:		
1-inch screen	8.5	34.6
3/4	17.5	23.8
1/2	34.7	25.3
1/4	31.3	12.2
1/8	5.9	2.2
Pan	2.1	1.9
Total	100.0	100.0
Chip thickness as determined by percent retained on screens with bars spaced at:		
11 mm.	1.7	31.8
9	2.3	17.5
7	8.9	17.9
5	24.5	18.9
3	42.5	10.0
Pan	20.1	3.9
Total	100.0	100.0

Figure 6. — Longleaf and slash pines with taproots attached, ready to load on trucks near Panama City.

Figure 7. — After extraction of all trees, the Cedartown site was free of stumps and debris. Skidder action has filled in most of the stump holes.

1974 and early 1975. From the various trials, the authors conclude that the concept and the hardware, with minor modifications, will prove usable throughout much of the southern pine region. These modifications may include lengthening the stroke of the lateral root shear, and increasing the area of the jack pad (Fig. 1, lower right) to prevent its indentation into the ground with consequent loss of jacking action. Because close trimming of lateral roots is desired by papermakers, it may be desirable to manufacture the shear in a range of diameters to match the sizes of trees harvested. The trials indicated that small trees may adhere to a knife after extraction; a more positive ejection mechanism may be needed to dislodge small stems from the gripping mechanism as they are bunched. Modification shown to be desirable by the trials will be incorporated in the machine by early 1975.

It is also recognized that substantial work needs to be done in devising total harvesting systems to cope with problems of complete-tree skidding, transport, bucking, dirt removal, and chipper maintenance.

In spite of these problems, it is likely that the industry will eventually adopt the concept. The main advantages seem to be:

- Pulpable tonnage per acre of plantation can be increased by about 20 percent.
- Site preparation costs for subsequent planting will be substantially reduced (Fig. 7).
- Hazard from black turpentine beetle should be significantly reduced by removal of stump-taproots from sites. It is speculated—but not demonstrated—that infection and spread of *Fomes annosus* may be inhibited in plantations from which stump-taproots are removed. Breeding of pine reproduction weevils may also be curtailed.

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