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Cover: Superior cultivated seeds produce more tree fiber in equivalent time periods as regular natural seeds and result in greater wood chip quantities for pulping. See details page 12.

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Harvesting Southern Pines With Taproots Is Economic Way To Boost Tonnage Per Acre 20 Percent

By Peter Koch
Chief Wood Scientist
Southern Forest Experiment Station

At the Southern Forest Experiment Station, we've been trying to extend the pulpwood resource by bringing more of each pine tree to the mill yard. The taproot of a 15- to 30-year-old southern pine weighs about 20% as much as the merchantable stem (Table I). Harvesting and pulping this wasted material would greatly increase pulpwood tonnage yield per acre. But is it feasible to do so?

To answer that question, we began a series of studies aimed at (1) determining if the taproot is physically and chemically suited for kraft pulping and (2) developing the needed harvesting machinery.

Taproots Suitable for Pulp

Pine taproots are carrot-shaped and generally 3 to 5 feet long. Maximum diameter occurs a few inches below ground level and is 1.5. to 2 times stem diameter at breast height.

In structure, rootwood varies considerably from stemwood. Roots make virtually uninterrupted growth throughout all 12 months of the year. Although distinct bands of latewood are sometimes found, growth increments are more often distinguished by several rows of radially flattened cells, whose walls may be no thicker than those of earlywood. Frequency, size, and distrubution of bordered pits in rootwood tracheid walls are more variable than in stemwood, and fibril angles may be larger. The pit structure is not likely to affect pulping processes greatly, but large fibril angles may lead to inferior paper properties. Except for a greater incidence of ray tracheids elongated perpendicularly to the rays and the virtual absence of thick-walled parenchyma cells, rootwood rays and resin canals resemble those of stemwood.

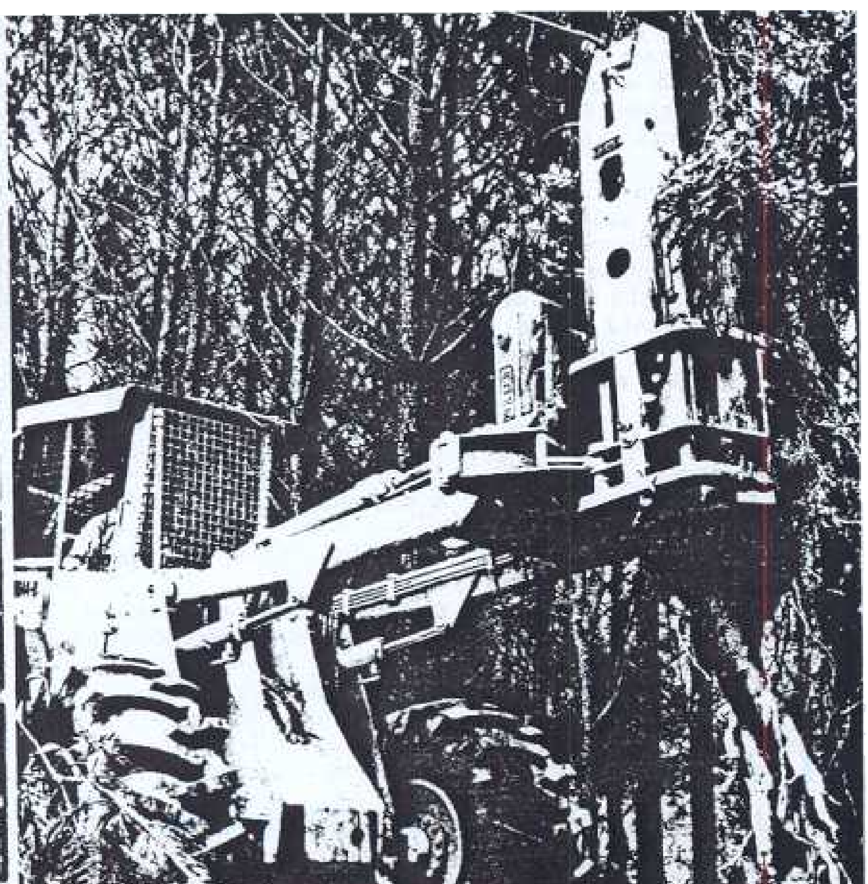

Fig. 1—Tree puller, showing typical functioning.

In a sample of 20 southern pines aged 12 to 89 years, Manwiller (1972) found that rootwood tracheids were one-third larger in diameter than stemwood tracheids measured at stump height; rootwood cell walls were 18% thinner, and lumens were almost two-thirds larger (Table II). Observations on the taproot of a single tree further revealed that all cell dimensions increased to a maximum at a point about 1.5 feet below ground level and then diminished. In this tree, minimums of length (3.2 mm), diameter (44 μ m), and wall thickness (4 μ m) occurred about 10 inches below the point where the maxima were observed.

To provide some data on chemical constitutients, Howard (1973) uprooted three 22-year-old slash pines growing in central Louisiana on well-drained sandy loam soil in an unthinned plantation. Lateral roots were severed at a radius of 3 feet. Rootwood had slightly more extractives, lignin, and ash and slightly less cellulose than stemwood (Table III). The roots had a moisture content of 111 percent and specific gravity of 0.38 (basis of unextracted, ovendry weight and green volume); stemwood averaged 116 percent in moisture content and 0.47 in specific gravity. In short, it seems likely that taproots of the southern pines are pulpable by the kraft process, a conclusion supported by the work of Sproull et al. (1957). Because of chemical composition, slightly lower yields than those obtainable from stemwood can be expected. More recently Keays (1974) concluded that use of naturally occurring percentages of stumps and roots of mature conifers would have little effect on strength of kraft pulps.

Moreover, roots are more suitable for pulping than either branches or tops; i.e., roots have higher alpha cellulose and lower lignin content than tops or branches (Table III). To take advantage of this wasted resource, a machine was designed to first shear the laterals close to the taproot and then pluck the entire tree from the ground (Koch and Coughran 1975, Koch 1976).

Tree Puller

The machine, manufactured by Rome Industries, Cedartown, Georgia, can be fitted through a quick-hitch mechanism on a number of prime movers—for example, a Caterpillar 920 or a John Deere 544B (Fig. 1).[1] 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.

With this grip anchor, the second element in the design comes into action. It is a clamshell-hinged tubular shear, 22 inches in diameter and made of 3/4-inch-thick steel. The 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 strike the ground and prevent further penetration. An additional stroke of the hydraulic cylinder raises the grips 9 inches while the steps remain 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 and bunched for skidding. Since shearing takes only a few seconds. a tree can be harvested and bunched in about half a minute.

Harvesting and Utilization System

To a considerable extent, the utilization system is controlled by dirt that adheres to the taproot. Such adherence is more severe in clay soils than in sandy soils. Much of this dirt is shaken free when trees are bunched, skidded, delimbed, and stacked (Fig. 2), but a significant amount remains. This residual dirt and adhering bark should be removed before chipping for pulp.

To this end, a harvesting system for pine plantations on sandy soils is proposed as follows:

- Trees are pulled entire and bunched.
- Bunched trees are thrust tops first through a delimbing gate (Fig. 3) and skidded to roadside.
- At roadside, tops and taproots are cut to 2- or 3-inch diameter inside bark with a chainsaw, and potentially troublesome stubs of lateral roots are trimmed.
- Complete trees are grapple-loaded (Fig. 2) onto trucks with 20-ton payload for transport to the mill. Grapple-loads of stems are alternated so that on one load the roots are forward and on the next to the rear; this procedure permits building a maximum-weight load without exceeding height limitations.
- At the mill, full truckloads of complete-free stems are fork-lifted into large cradles for subsequent mass bucking (with bundle-bucking chainsaws) into 8-foot pulpwood lengths.
- The 8-foot pulpwood, as it is bucked, falls onto a chain conveyor leading to a drum debarker.
- All pieces are cleaned of dirt and debarked in the drum debarker; bark (with considerable dirt content) is conveyed to the powerplant through cleaning equipment to reduce dirt content to levels tolerable by the burning equipment.
- Bark-free (and remarkably dirt-free) wood emerges from the drum debarker to pass through disk chippers and hence into the pulp mill.

This procedure is summarized in Figure 4.

The harvesting cycle is completed

Table I.—Weight distribution (ovendry basis) in three 22-year-old, 7.7-inch, unthinned, plantation-grown slash pine trees cut in central Louisiana[a]

Portion of tree	Weight fraction (percent): Total tree	Weight fraction (percent): Bark-free stem to 4-inch top (dob)
Bark-free stem	58.5	100.0
Taproots and stump	11.7	20.0
Lateral roots to 3-foot radius	4.8	8.2
Stem bark to 4-inch top	12.5	21.4
Top (with bark)	5.0	8.5
Needles	4.0	6.7
Branches (with bark)	3.5	5.9
Total	100.0	

a Adapted from Howard (1973).

Table II.—Mean tracheid dimensions in root and stumpwood of 20 southern pines[a]

Dimension	Stumpwood[b] Mean	Stumpwood[b] Standard deviation	Rootwood[c] Mean	Rootwood[c] Standard deviation
Length (mm)	3.0	0.64	4.0	0.89
Cell diameter (μ m)	38.8	9.39	52.5	12.21
Lumen diameter (μ m)	25.7	11.06	41.7	13.08
Wall thickness (μ m)	6.6	2.15	5.4	1.67

a Data from Manwiller (1972).
b Stumpwood sampled from two opposed 20-degree wedges (1-inch thick) removed 18 to 24 inches above ground level.
c Sampled from disks taken along the taproot beginning at the point where major laterals were attached.

1 Mention of trade names is solely for information purposes and does not imply endorsement by the U.S. Department of

by replanting the well-prepared site. Holes left after harvesting vary from inconspicuous indentations to cavities 22 inches wide and a foot deep. Skidding activity in combination with normal rainfall partially fills most holes.

Cost of Wood Delivered to Mill

The harvesting system envisioned (Fig. 4) is designed for clearcutting unthinned stands perhaps 25 years old that average about 8 inches in dbh (12-inch maximum on any tree). It is assumed that each acre carries 500 trees averaging 600 pounds in green weight when shorn of limbs and lateral roots. Puller-buncher productivity with an experienced operator should average two trees per operating minute (Fig. 5).

Equipment Cost And Depreciation

Total investment in equipment should be approximately as follows:

Machine	Cost
Puller-buncher	$60,000
2 grapple skidders	86,000
Portable delimbing grate	1,000
Roadside grapple loader	31,000
4 set-out log trailers	24,000
2 diesel truck-tractors	64,000
Support truck	15,000
Investment in system	$281,000

Under 5-year straight-line depreciation with 10% residual value, annual depreciation is

$$\frac{\$281{,}000 - 28{,}100}{5 \text{ years}} = \$50{,}580$$

The equipment in the system is simple, highly practical, and thoroughly field-tested; therefore, all four woods machines in combination should be mechanically functional (available) 75 percent of the time. Of this available time, they should be operating 75 percent of the time. Net operating time is thus 0.75 availability x 0.75 utilization, or 0.563 hour out of every scheduled hour.

The machines will be scheduled 5 days per week, 8 hours per day, 48 weeks per year (allowing 4 weeks for vacation and holidays). Thus, a total 1,920 hours will be scheduled each year. Actual operating hours will therefore total 0.563 x 1,920 hours, or 1,081 hours per year.

At two trees per operating minute and 500 trees per acre, 0.24 acre should be harvested per operating hour. Acres harvested annually should therefore total 259.

Labor Cost

Seven men are needed to operate the harvesting and delivery system. Cost of manpower, including supervision (but excluding mechanic's labor, which is covered under operational expense) should total about $112,000:

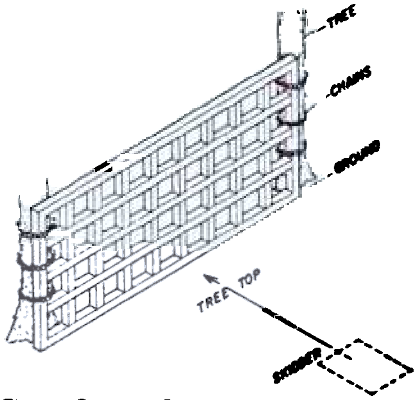

Fig. 3 — Grate-type delimber. Bunched trees are thrust tops first through this apparatus, which shears limbs from the stems.

Function	Annual cost including fringe benefits
4 machine operators at $15,000 each (for puller-buncher, 2 skidders, and grapple-loader)	$60,000
1 chainsaw operator at the landing	15,000
2 truck drivers	30,000
Supervision (assumes supervisor is handling 3 or 4 logging sites)	7,000
Total labor	$112,000

Operational Expenses

Annual operating expenses for oil, fuel, maintenance, and parts should be about as follows:

Machine	Annual cost (1,081 operating hours)
Puller-buncher, $16 per hour	$17,296
Two grapple skidders, $14 per hour each	30,268
Roadside grapple loader, $12 per hour	12,972
Two tractor-trailer highway trucks (with 4 trailers), $24 per hour	25,944
Supper truck, $6 per hour	9,000
Total	$95,480

This total is 1.9 times annual depreciation charge.

Total Annual Costs

Item	Amount
Depreciation	$50,580
Labor and supervision	112,000
Oil, fuel, maintenance, and parts	95,480
Total	$258,060

Annual Cash Benefits

Benefits from the system include site preparation, here assumed to be $30 per acre, as well as receipts for wood:

Item	Amount
Site preparation $30/acre x 259 acres/year	$7,700
Complete-tree stems delivered to mill $6.4443/ton x 500 trees/acre x 0.3 green ton/tree x 259 acres/year = $6.4443/green ton x 38,850 tons/year	250,360
Total	$258,060

From the foregoing computation, it is evident that harvesting costs of $6.44 per green ton delivered result from this system.

Profit on Capital

If 30% profit on investment (before income taxes) is required, annual profit must amount to 0.3 x $281,000, or $84,300. If this profit is allocated over the 38,850 tons of green pulpwood delivered to the mill each year, it amounts to $2.17 per green ton. Pulpwood price, delivered to mill yard (including woodlands profit on equip-

Table III.—Chemical composition (percent) of rootwood and other tree parts averaged for three 22-year-old slash pine trees[a]

Component[b]	Roots	Top	Branches	Bark-free stem to 4-inch top (dob)
Extractives[c,d]	11.7	11.0	13.6	9.1
Alpha-cellulose[e,f]	44.6	41.5	36.9	51.1
Hemicellulose[e,f]	25.6	31.2	33.7	26.8
Lignin[e,g]	31.3	32.5	35.1	27.8
Ash[c,h]	1.6	.8	1.2	.3

[a] Data from Howard (1973).
[b] Summations exceed 100 percent because of overlapping solubilities.
[c] Percent of unextracted ovendry weight.
[d] TAPPI Standard T6 os-59.
[e] Percent of extractive-free ovendry weight.
[f] Erickson's sodium chlorite method.
[g] By the analytical method used (Moore and Johnson 1967), other acid-insoluable substances would also be reported as lignin.
[h] Nitrated, then ashed at 480°C for 6 hours.

ment investment) should therefore be $6.44 plus $2.17, or $8.61 per green ton, plus stumpage price.

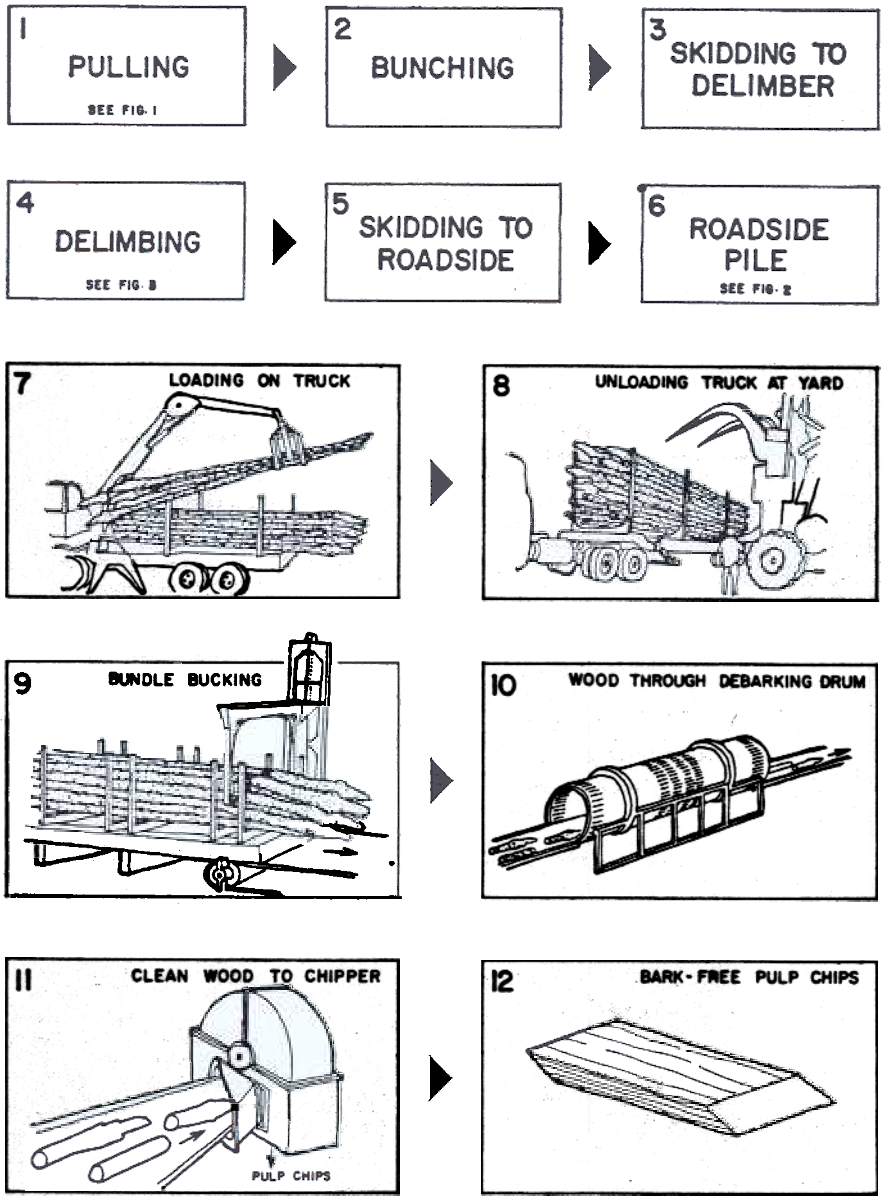

Fig. 4—Harvesting and utilization system.

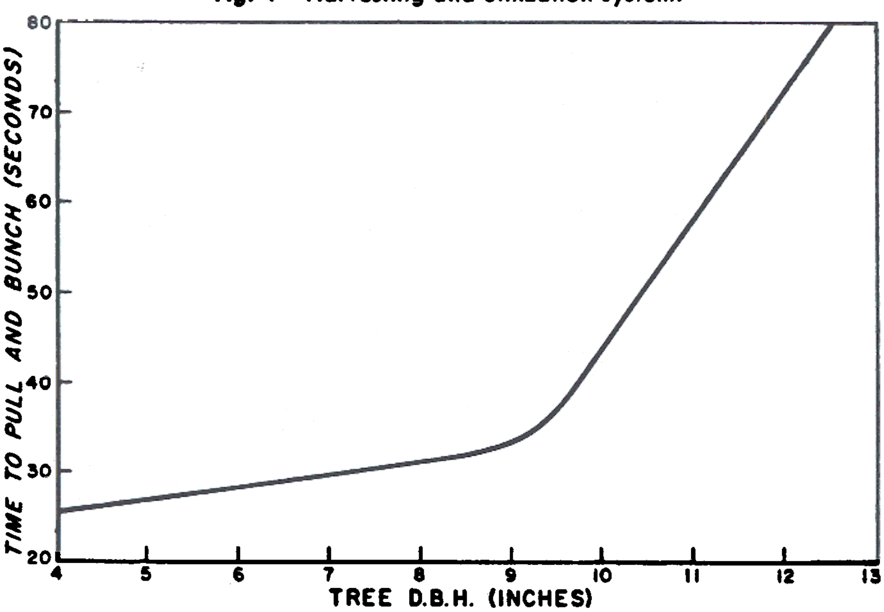

Fig. 5—Relationship between tree dbh and time to pull and bunch plantation-grown loblolly pines 15 years of age. (Data source: D. M. Tufts, Pineville Kraft).

Conclusion

One can draw the following conclusions about harvesting even-aged southern pine plantations with about 500 trees per acre averaging 8 inches in dbh and weighing 600 pounds green when stripped of lateral roots and branches:

- Using a puller-buncher instead of a feller-buncher should increase pulpwood tonnage harvested per acre by about 20 percent.
- Drum debarkers can clean bark and dirt from pine taproots and stems so harvested.
- Bark-free rootwood mixed with stemwood in its naturally occurring proportions should not adversely affect kraft pulp properties in any important way.
- Harvesting equipment for a tree-pulling system will likely cost about $281,000; the equipment needed includes a tree puller-buncher, two grapple skidders, two log trucks, four set-out log trailers, and a support truck. With this system, about 259 acres can be harvested annually during 48 forty-hour weeks.
- Cost of wood (including stem bark) so harvested and delivered to the mill yard, including 30% pre-income-tax profit on equipment investment, should be about $8.61 per green ton plus cost of stumpage.

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