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FEASIBILITY OF HARVESTING SOUTHERN HARDWOOD TREES BY EXTRACTION

by

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SUMMARY:

A Rome TXH Tree Extractor was used to explore the harvesting of four species of southern hardwoods by extraction. The test indicate that harvesting by extraction is feasible for harvesting, if tree size is limited to 9 inches DBH or less. Stump and below ground biomass averaged 18 percent of total tree biomass.

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INTRODUCTION

In an effort to increase the total fiber yield from the harvesting of forest trees, the concept of complete and total tree harvesting has been investigated by Young (1974). The complete tree concept is to use as much of the tree biomass, from both above and below ground, as possible. Practice of this concept would reduce the pressure now being exerted on commercial forest lands to meet world needs for forest products. In the United States the concept has progressed to the point where a machine has been developed for harvesting plantation-grown southern pines by extraction. As described by Koch and Coughran (1975) the machine severs the lateral roots of the tree and then extracts by pulling the "complete" tree, including the central root mass. This harvesting method can increase the amount of southern pine fiber available by approximately 20 per cent.

Besides pines, most commercial forest land in the South also contains many hardwood trees. If complete utilization of these hardwoods is to be realized, data-on the total harvestable biomass available from these trees should be collected now. It is also important to begin determining how this potential resource can be harvested. The study discussed in this paper is one of the first steps.

A TXH Tree Extractor manufactured by Rome Industries of Cedartown, Georgia, was used for the study because it was available and is being made commercially. The TXH was designed for harvesting plantation-grown pulpwood-size pine trees, not hardwoods growing in natural stands. Because of the wide gap between the TXH design purposes and this study no production data were collected. Machine data collected was for shearing and pulling forces. The test provides a good basis for development of future harvesting systems and provides information on how much stump and below ground biomass can be harvested for southern hardwoods.

PROCEDURES

Tree-Site Selections

The species selected for this study were sweetgum (*Iquidambar styraciflua* L.) true hickory (*Carya tomentosa* Nutt, C. *glabra* (Mill.) Sweet, southern red oak (*Quercus falcata* Michx), and white oak (Q. *alba* L.). These species were selected because they have high commercial value, provide a good range of specific gravities (soft to hard wood) and frequently occur on the same sites.

For each site 10 trees of each species were selected in three diameter classes: 1) 4 to 6 inches DBH, 2) 7 to 9 inches DBH, and 3) 10 to 12 inches DBH. With few exceptions selected trees were dominant or co-dominant in crown form. In the 4-to 6-inch class it was necessary to include some intermediate trees. An effort was made to be as random as possible, so some trees were selected that were growing close to another tree as long as there was room for the head of the tree extractor to.work. Selecting adjacent trees was avoided if it was judged that extraction of the first tree would affect extraction of the second tree. Trees with obvious butt defects were avoided.

Two sites were selected for the study. The basis for these selections were: 1) they contained the sizes and number of trees needed for the study, 2) soils were representive of the Southern Coastal Plain (sandy-loam) and Piedmont (clay-loam), 3) slopes were slight, not over 15 percent, to minimize equipment stability problems, and 4) timber stands were representive of typical mixed upland hardwoods and pines.

Data

Data collected included those necessary to provide a measure of the machine forces and times that they acted on a tree during extraction attempts. These data include time and force to shear lateral roots to a depth of 10 inches, and the time and force required to break or pull from the soil any unsheared roots for extraction. Forces were calculated from hydraulic system pressures acting on the shear-lift cylinders.

Soil parameters that could affect tree resistance to extraction were measured. These data included: 1) an indication of soil shear strength measured with a 1/2-inch diameter cone penetrometer, 2) wet bulk density, 3) dry bulk density and 4) moisture content of the soil.

At the time of extraction the soil moisture and density values were measured with a Troxler Model 3411 Nuclear Moisture-Density Gauge. Measurements were made at the soil surface, and at 6- and 12- inch depths. The penetrometer readings were also taken at the surface and at 6- and 12- inch depths.

To determine the percentage increase in wood fiber obtained from extraction of the stump during harvesting, we took green weights of tree components in the field within 15 minutes of extraction. Weight data included stump weight with and without soil, weight of tree from 6-inch stump height to 3-inch top without branches, and crown weight (including all branch wood).

Tree dimensions measured were length of extracted root to a 6-inch stump, total height, crown height, and height to 3-inch top. Diameters outside bark (DOB) were measured at 6 inches above ground line, breast height, base of crown, and mid height (1/2 of total height). At the time of measurements sample disks were cut from the tree butt, midpoint, 3-inch top, and branches for measurement of wood density and moisture content.

Test Methods

Before the test, the sample trees were selected and tagged to ensure that the numbers of trees of each species and DBH class were available on each site. Before attempting to extract a tree the soil parameters in its vicinity were measured with the cone penetrometer and the moisture-density gauge. The machine was then brought up to where the extraction head had clear access to the tree and where, if the tree was growing on a slope, the machine itself was stable (Fig. 1).

Figure 1. TXH Tree Extractor in position for gripping and extracting a tree.

The extractor was then closed around the tree, causing the horizontal grip blades to bite into the tree. With the extractor locked onto the tree, the two vertical semi-circular shears were activated and hydraulic pressure recorded for shearing lateral roots to a depth of 10 inches, the limit of the shear travel. After the 10 inches of penetration of the shear through the root system and ground, a force is applied by the same cylinders to begin extraction. For only a few small trees was this force by itself sufficient for extraction. Therefore, for this test the primary extraction force was considered part of the shearing force. In most cases it was necessary to apply additional force by use of the loader lift arms. In these cases this secondary force was recorded as the extraction or pulling force.

To collect data for the harvestable below ground biomass of the root crown, we sometimes used other techniques to extract trees that were not easily **pulled** on the first attempt. These techniques included making a second attempt at right angles to the first, rocking the tree by use of the loader tilt cylinders, and rocking the total machine while applying an upward force with the lift arms. Usually if the tree could not be extracted within 3 minutes the attempt was recorded as a failure.

For trees that were pulled, the tree components were separated with a chainsaw, and the tree data were recorded. The stump (6-inch height) and root crown were considered one unit. The stump unit was weighed with soil that remained on the root system after extraction. To obtain a clean unit for weighing, we used steel bars and, when necessary, a high pressure water stream to remove soil and rocks from the root system (Fig. 2).

Figure 2. Manually cleaning soil and rocks from a white oak stump.

RESULTS AND DISCUSSION

Early in the test it became apparent that we would run into more difficulties in trying to extract hardwoods than Koch (1976) reported for southern pines. The first tree attempted was a 49-year-old hickory with a 7.8 inch DBH. It took a total of 24.21 minutes in two attempts, 90 degrees to each other, to extract this tree. The force required to shear the lateral roots was 90,400 pounds. The extraction force provided by the second half of the travel of the shear-extraction cylinders was either not sufficient at 147,000 pounds, or the force was not applied over a long enough stroke to break the lateral and tap roots that were below the lo-inch travel of the shears (Fig. 3).

Figure 3. Twisted and broken hickory roots that were not sheared.

Observations during the time of the test indicate that lack of shear and extraction cylinder stroke, not available force, prevented easy extraction of this tree and others during the test.

Extraction Forces

Of the 120 sample trees selected for test it was possible to pull only 75 trees. The average values for these trees are shown in Table 1. Hickories were the most difficult of the four test species to harvest by extraction. For the clay loam site (MH) it was not possible to extract any of the five sample trees in the 7-9 inch DBH class. The one 10-12 inch hickory that was extracted on this site did not appear to have the deep tap root characteristic of other extracted hickories. So once the lateral roots near the surface were sheared, the tree was extracted with little difficulty considering its size. White oaks and sweetgums followed the hickories in difficulty of extraction, with no clear distinction between the two. Considering average DBH for the pulled trees and the pulling forces necessary the red oaks on both sites were the easiest of the four species to extract. Once the lateral roots near the soil surface were sheared the tree could easily be extracted without working the machine near its limits.

We made regression analyses to determine if there was a linear correlation of shearing forces and pulling forces to DBH (Tables 2,3). Only the white oaks on the sandy loam site show a low degree of correlation. Re-examination of the field data gave no clues as to why the white oak correlation was lower than that of the other three species.

Of the soil parameters measured, the cone penetrometer readings indicated the greatest variation within a particular test site. However, variation appeared to be no greater for the white oaks than for the other species. At the 6-inch depth there was a difference between the two soil types. For the sandy loam (T) sites the cone index readings ranged from a low of 90 to a high of 235 with a mean of 145. The clay loam (M) sites ranged from 75 to 180 with a mean of 128.

The within site soil moisture readings for the test areas were generally lower than the proposed test range of 15 to 25 percent. For the sandy loam site the average for the test area was 15.3 percent. The within site averages for the sweetgum and white oaks were high at 15.8 and 16.7 percent respectively. For the clay loam area the soil moisture content averaged 19.1 percent. Again the sweetgum and white oaks were on the wetter sites of the area with average moisture contents of 20.5 and 19.7 per cent respectively.

Soil density for both areas showed little within area variation. The average value for the sandy loam area was 84.3 pounds per cubic foot (dry) and the clay loam area was 87.6 pounds per cubic foot (dry).

Table 1. Average Force Values for Extracted Trees

Site Species	DBH Class	Average DBH	No. of Trees	Average Shearing Force lbs.	Average Pulling Force lbs.
TG	4-6	5.8	2	79,000	20,200
TG	7-9	7.4	3	68,000	30,008
TG	10-12	---	-0-	------	------
MG	4-6	5.1	7	56,520	21,100
MG	7-9	8.0	3	90,400	32,300
MG	M-12	10.5	1	141,300	32,300
TH	4-6	4.9	6	59,300	27,300
TH	7-9	7.8	6	80,300	35,000
TH	10-12	---	-0-	------	-----
MH	4-6	4.9	6	62,200	25,300
MH	7-9	---	-0-	------	------
MH	10-12	10.6	1	169,600	32,300
TR	4-6	5.3	7	53,700	17,500
TR	7-9	8.6	5	90,400	25,900
TR	m-12	10.7	4	113,000	34,300
MR	4-6	5.4	4	60,800	20,200
MR	3-9	7.8	4	101,700	25,500
MR	10-12	10.9	1	118,700	33,600
TW	4-6	6.3	3	86,700	30,900
TW	f-9	7.8	5	76,900	28,200
TW	10-12	---	-0-	------	------
MW	4-6	4.8	3	62,200	25,500
MW	7-9	7.7	4	93,300	31,600
MW	10-12	---	-0-	------	-------

Notes: T = sandy loam site, M = clay loam site
G = sweet gum, H = true hickory
R = Southern red oak, W = white oak

Example : TG = sweet gum on sandy loam site

Table 2. Regression analyses of shearing extraction forces vs. DBH [SF = bo + b (DBH)]

Site Species	Equation	r^2	Sample Size
TG	SF = 45,722 + 5,633 (DBH)	.996	3
MG	SF =-21,391 + 14, 586(DBH)	.877	10
TH	SF = 20,517 + 7,869 (DBH)	.609	9
MH	SF = 16,118 + 16,632 (DBH)	.809	6
TR	SF = -8,437 + 11,940 (DBH)	,706	9
MR	SF= -4,560 + 12,734 (DBH)	.765	9
TW	SF = 93,745 - 1,824 (DBH)	.027	8
MW	SF = 18,477 + 9,539 (DBH)	.599	7

Table 3. Regression analyses of pulling force vs. DBH [PF = bo + b (DBH)]

Site Species	Equation	r^2	Sample Size
TG	PF = -29,120 + 8,067 (DBH)	,628	4
MG	PF = 6,633 + 2,848 (DBH)	.616	10
TH	PF = 19,200 + 1,972 (DBH)	.647	9
MH	PF = 18,732 + 1,331 (DBH)	,599	6
TR	PF = 3,285 + 2,769 (DBH)	.578	10
MR	PF = 8,347 + 2,221 (DBH)	.580	9
TW	PF = 24,184 + 697 (DBH)	.011	8
MW	PF = 11,624 + 2,574 (DBH	,493	6

It does not appear that any site variable significantly affected extraction forces. Factors such as whether or not a tree had grown from an old stump sprout are difficult to account for. Sometimes, if trees had grown from stump sprouts, a large portion of the root system was sheared off and extraction effort needed was reduced. When the old root system was not sheared, extraction effort required was increased.

To check the total effects of site on the shearing-extraction forces we combined the data from both test areas for each of two species, hickory and sweetgum. Then regression analyses were made for each species. The result was the lowering of the correlation coefficient. The results of these analyses are:

Hickory (TH + MH) sample size = 15 $r^2 = .463$

$$PF = 17440 + 1897\ (DBH)$$

Sweetgum (TG + MG) sample size - 14 $r^2 = .562$

$$PF = 5073 + 3129\ (DBH)$$

These equations should be a more general representation of the pulling forces than those of Table 2 because they were developed from a broader data base.

Extraction Failures

From Table 1 it can be seen that only three trees were extracted in the 10-12 inch DBH class. Trees in this size class were generally too large for the TXH Tree Extractor and in a number of cases trees of the 7-9 inch class also proved too difficult for the machine. Three factors that are not problems with pines complicated extraction of these trees.

First, hardwoods tested, with the exception of sweetgum (Fig.4), had more lateral, roots at greater depths than pine. The TXH is only capable of shearing lateral roots to a depth of 10 inches and a number of lateral roots existed below this level (Figs. 5,6).

A second area that contributes to extraction difficulty is butt swell. For trees in the 7-9 and 10-12 inch DBH classes this swelling prevented the extractor head from closing completely and also prevented the horizontal knife grippers from holding. Figure 7 shows the results of not being able to close the head completely. When this occurs the root shears have a gap in both the front and back of the head. If a lateral root happens to be in the location of the gap it is not sheared. Table 4 gives the regression analyses for butt swell as related to DBH. These relationships are shown in Figure 8.

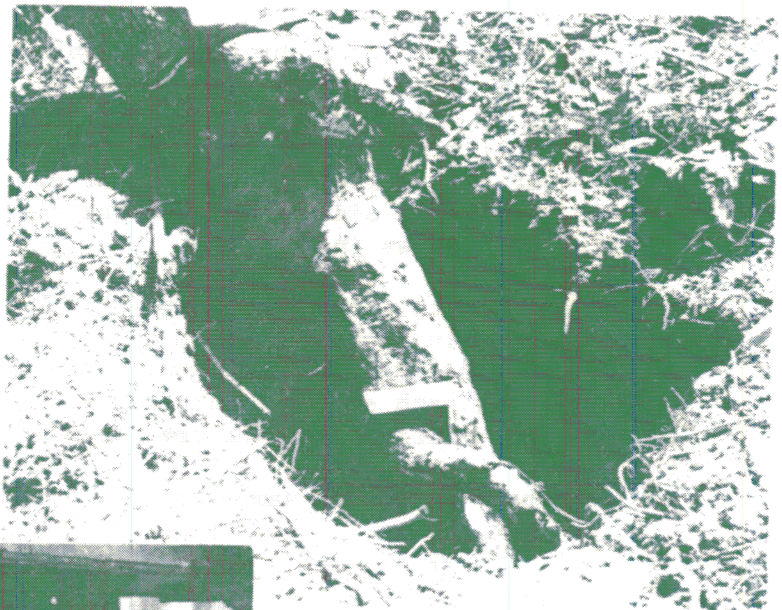

Figure 4. Large carrot shaped tap root of a sweet-gum with only minor lateral roots near the soil surface.

Figure 5. Massive lateral root system of a 7-9 inch DBH hickory with lateral branching at 40 inches in depth.

Figure 6. Unsheared lateral root system at 20 inches for a 7-9 inch DBH white oak.

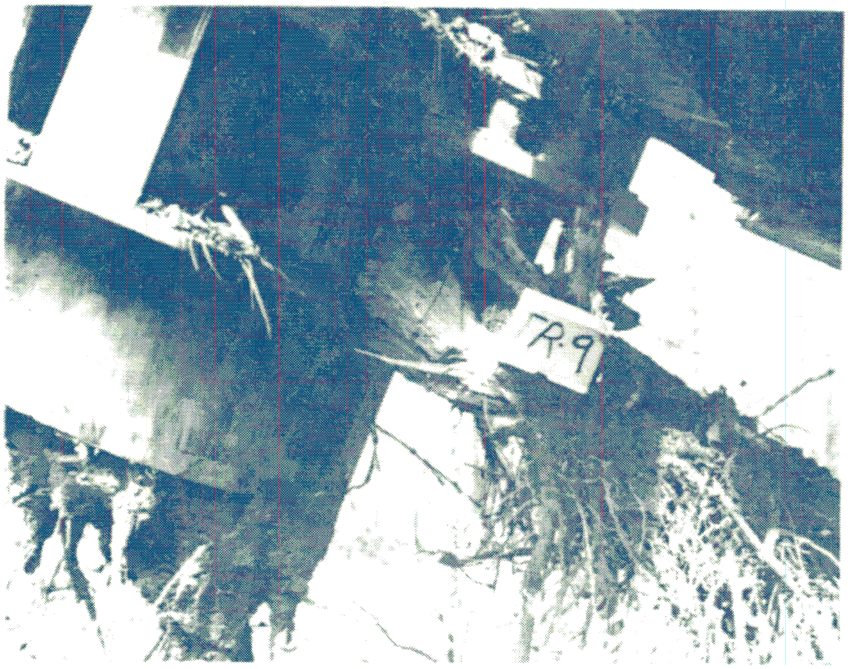

Figure 7. Large unsheared lateral root in the gap between the shears

Table 4. Linear regression analysis of butt diameter at 6 inches to DBH

Site Species	Equation	r^2	Number of Samples
TG	BD = -3.239 + 1.736 (DBH)	.970	5
MG	BD = 0.123 + 1.232 (DBH)	.968	11
TH	BD = 0.221 + 1.276 (DBH)	.870	12
MH	BD = 0.933 + 1.102 (DBH)	.957	6
TR	BD = 1.828 + 0.992 (DBH)	.963	16
MR	BD = -0.319 + 1.386 (DBH)	.806	9
TW	BD = -0.254 + 1.389 (DBH)	.901	8
MW	BD = -0.659 + 1.617 (DBH)	.778	7

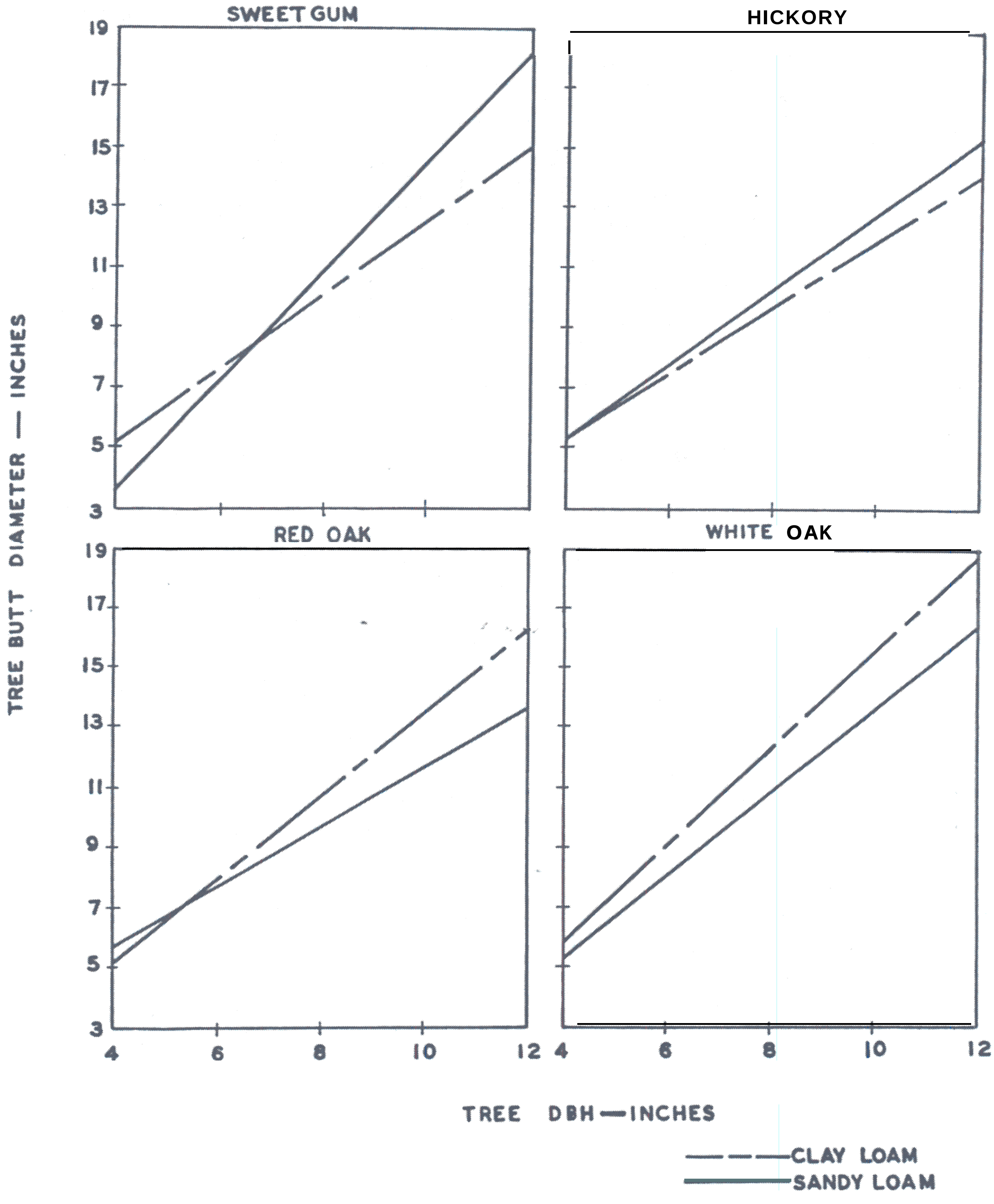

Figure 8. Relationships of Butt swell to DBH for Southern Hardwoods.

A third problem, also related to butt swell, is shown in Figure 9. In these cases the wood above the gripping point fails, permitting the whole extractor head to move up the tree. These failures generally occurred during the cycle for shearing of the lateral roots. For the root shears to be effective the gripping force must exceed the upward force on the head that results from resistance to root cutting.

Figure 9. Failure of the wood above the tree grippers.

Another cause of failure to extract trees was inaccessibility. This failure occurred most frequently for the white oaks and sweetgums growing on the lower wetter sites. The total weight of the Caterpillar 930 loader and TXH Extractor was approximately 30,000 pounds. This weight in combination with the Goodyear Timber Torque 23.1-26 tires that the loader was equipped with, provided an estimated ground pressure of about 10 psi. With this seemingly low ground pressure we found that it was easy to get stuck. On most of the lower sites it was possible to travel over the same tracks twice, but on a third trip or if the machine had to be rocked forward and backward to aid extraction, the tires would break through the vegetative mat. Once this happened it was necessary to retreat as soon as possible to avoid becoming stuck. On several occasions the tires had sunk to a depth of about 18 inches. When this happened it was difficult for the 930 loader to pull its way out of its own ruts because of torque converter stall. In these cases it was necessary to abort attempts at extraction of the sample tree.

Harvestable Biomass

Table 5 presents average weights of harvested biomass with root biomass shown as a percentage of above ground biomass (main stem, crown, and branch wood), and as a percentage of total tree biomass. The stump and root wood values as a percentage of above ground biomass are comparable to the average values reported by Koch (1976) of 18 to 22 percent for pines.

Table 5. Average Harvested Biomass

Site Species	Total tree Biomass (lbs.)	Stump Root Biomass (lbs.)	Percent of Total Above Ground Biomass	Percent of Total Biomass
TG	478	79	19.8	16.5
MG	444	84	23.3	18.9
TH	577	104	21.9	18.0
MH	514	94	22.4	18.3
TR	766	124	19.3	16.2
MR	660	94	16.6	14.2
TW	678	164	31.9	24.2
MW	532	90	20.4	16.9
Overall Averages	581	104	22	18

The below ground biomass values from this study varied widely between and within species with spreads of up to 39 percent in the case of red oaks. With few exceptions the greatest within species variations in percentage of harvested biomass were for the smaller trees in the 4-6 inch DBH class. These variations should be expected because when a tree is extracted it is possible that only a small portion of the total root system might be harvested. If the tree grew from a sprout, as shown in Figure 10, part of the roots and stump may be sheared off. Also, if the extractor head did not close completely, a large lateral root could be included in the harvested biomass. These are mechanical factors and do not account for the probable natural variations in the root size.

Figure 10. Approximately 50 percent of stump wood was unharvested.

CONCLUSIONS

Based on this study I believe harvesting by extraction of southern hardwoods up to approximately 9-inches DBH is technically feasible. Economic feasibility cannot be judged at this time. A great deal will depend upon future demands for the additional harvestable fiber available in the root crown and stumps of hardwoods. Harvesting cost will also be a major factor in determining economic feasibility. How much of this harvesting cost can be charged against future site preparation cost will also influence feasibility.

Future development of an operational hardwood tree extractor would require several changes from the TXH Extractor. First, a lower-ground-pressure prime mover is needed with a higher draw bar capability than that of normal wheeled loaders, To keep the machine size and cost within reason an upper limit on tree size should be established at about 9 inches DBH. By limiting tree size to 9 inches DBH the present tree gripping method of the TXH should be adequate; however, additional force is needed to insure complete penetration of the gripper blades. The depth of shearing of the lateral roots should be Increased or a method for shearing the tap root at a depth of about 20 inches should be developed. Of the four test species, the change is mainly needed for hickory and sweetgum.

A shearing force and primary extraction force of 180,000 pounds, similar to the maximum design capability for the TXH Tree Extractor, would provide fur reliable extraction if the extraction force could be applied over a greater distance? than the maximum 10 inches for the Tree Extractor.

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