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TB17: Fiber Weight and Pulping Characteristics of the Logging Residue of Seven Tree Species in Maine

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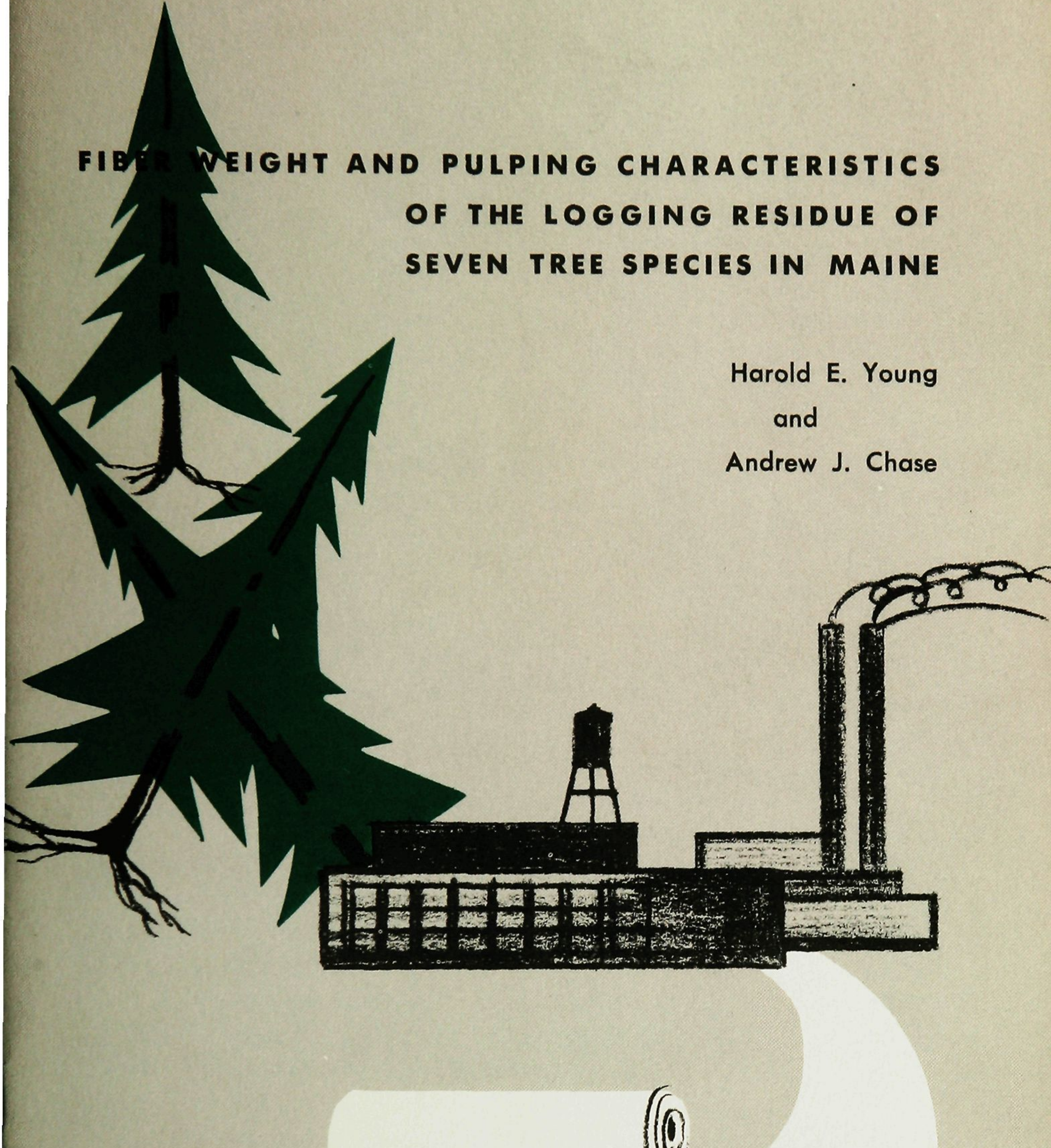

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Foreword

In the past five years a number of students have worked on various phases of the complete tree under the direction of Professors Harold E. Young and Andrew J. Chase. Some of the results have been published in TAPPI or in Maine Agricultural Experiment Station bulletins and some are unpublished.

The accumulation of evidence concerning the amount of fiber in the present logging residue and the pulping potential of that residue justifies this synthesis of the various studies in a single publication. Only a small amount has been done and there is much to be done. This compilation of available information is presented to encourage a more widespread effort in this direction for without it the likelihood of meeting the paper requirements of the rapidly growing American public fifty years hence is negligible.

A. D. Nutting
Director, School of Forestry

Acknowledgments

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FIBER WEIGHT AND PULPING CHARACTERISTICS OF THE LOGGING RESIDUE OF SEVEN TREE SPECIES IN MAINE

Harold E. Young and Andrew J. Chase[1]

WEIGHT STUDIES[2]—Harold E. Young

The present highly productive farms of Ohio, Indiana and Illinois were virgin hardwood forests about 160 years ago when the pioneers moved from the eastern seaboard to settle that region. The large trees presented many problems in land clearing as only simple tools, horses, oxen, manpower and ingenuity were available. Large stumps and butt logs were so troublesome to burn that, whenever possible, they were buried in ravines to simplify matters. Black Walnut (Juglans nigra L.) is excellent material for gun stocks and furniture and is now in such limited supply that locating and uncovering buried stumps and logs is a highly lucrative commercial venture. Thus in the span of 160 years this tree species has changed from an undesirable nuisance to a highly desired prize.

This incident dramatically characterizes an evolutionary process in the importance of forests and forest products that is not unique to the United States. It is becoming increasingly apparent that at some future time the annual cut will equal or exceed the annual growth in the United States. In its most recent report the United States Forest Service (1958) presented a somewhat gloomy picture of the future because of the unbalanced distribution of size classes within major tree species, overcutting some species and undercutting others. According to Behre (1949) there were about 660,000,000 acres of commercial forest land in the United States in Colonial days; this has been reduced to 460,000,000 acres due to agricultural and urban development. Since 1900 there have been many major improvements in agricultural practices that have sharply reduced the total amount of tilled land, but have been offset by the development of cities, airports and the construction of highways and power lines. Government officials have estimated that the present population of about 190,000,000 people will increase to about 300,000,000 by the year 2,000. Such an increase in population in less than 40 years is bound to increase urban and road development resulting in continued decrease in the available forest area.

There have been many wood substitutes developed in the past half century. Despite this wood continues to be the primary material for

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paper and as the world becomes more literate the annual consumption of paper continues to increase. The U. S. Forest Service estimates that the American consumption of wood for all purposes in the year 2,000 will be between 64-73 cubic feet per person which is a reduction from the 79 cubic feet per person consumed in 1952. Despite this reduction the population will have increased so extensively that the annual consumption of wood will be at least 80% greater in the year 2,000 than it was in 1952.

Where will the wood come from? It will come in part from intensive forest management, and in this respect the United States can learn much from Europe. It will come in part from forest genetics research with the goal of developing better and faster growing trees. It will come in part, and probably the largest part, from increased utilization of that portion of the felled tree that is currently removed from the forest and from the logging residue of the felled tree that is presently left in the forest.

Utilization of logging residue must be considered in three progressive steps. The first is the possible products that can be made from such material. The second is the magnitude of the logging residue. The third is the development of harvesting and manufacturing equipment provided that the results of the first two steps indicate the desirability of exploring the third step and provided the third step can culminate in an economically sound solution. This paper will summarize two studies (Young et al, 1963, Young et al, 1964) concerning the second stage: the amount of logging residue remaining in the forest after harvesting.

Methods

During the summer of 1962 field procedures were developed and established while working with Red Spruce (Picea rubens Sarg.) in the University Forest, Stillwater, Maine. Data for Red Maple (Acer rubrum L.) was obtained in the same forest the same summer. In the University Forest during the summer of 1963 similar data were obtained on Balsam Fir (Abies balsamea (L.) Mill.), White Pine (Pinus Strobus L.), Hemlock (Tsuga canadensis (L.) Carr,) White Birch (Betula papyrifera Marsh.) and Aspen (Populus sp. L.).

Tree selection for each species in Maine was designed to provide a range in diameters from six inches to the largest found in the forest and corresponding total heights (table 1.) For this study no attempt was made to confine tree selection to a single site and/or a single density, but it is reasonable to state that all of the stands in Maine from which trees were selected were fully stocked and the soil was a stony till. The

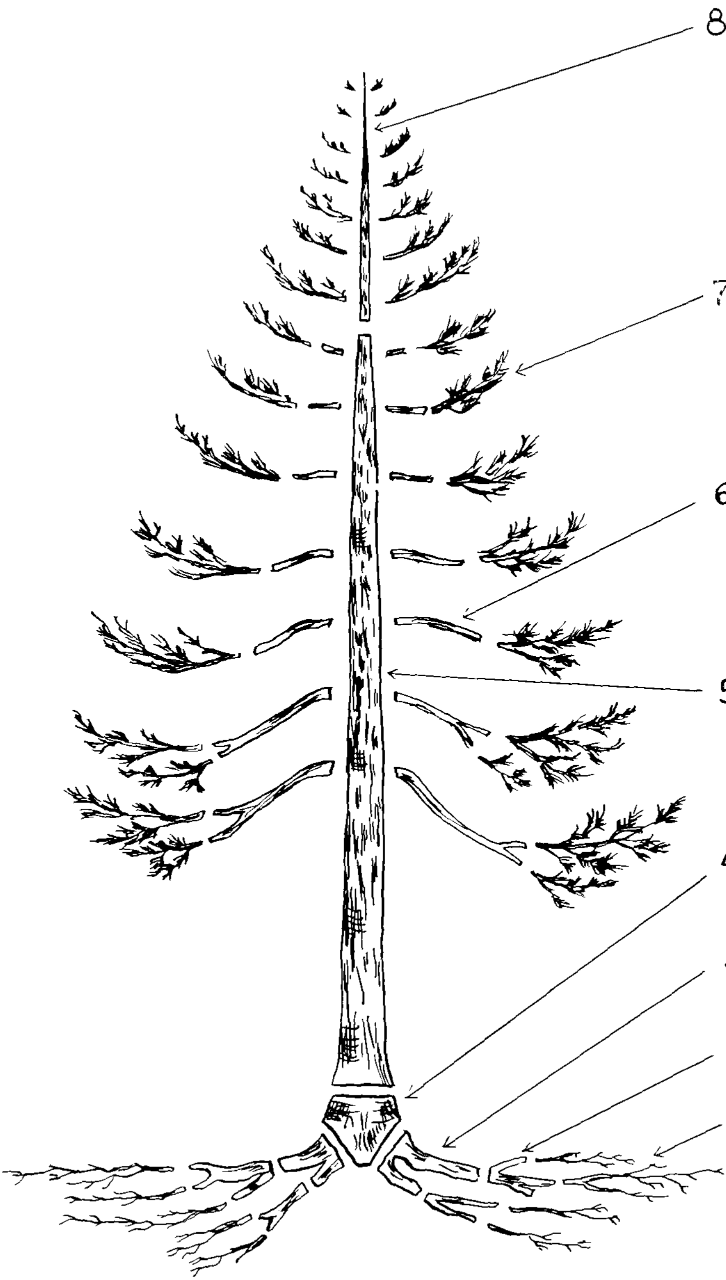

Figure 1. Diagrammatic sketch showing the eight components of a tree

accessibility of the selected trees to existing roads from the standpoint of using the tractor was a factor in tree selection.

For weighing purposes the tree (fig. 1) was divided into the following eight categories:

1. small roots less than one inch including rootlets
2. roots one to four inches in diameter
3. roots larger than four inches
4. the stump
5. the merchantable bole to a diameter limit of four inches
6. all branches down to one inch in diameter
7. branches less than one inch including all branchlets and leaves /needles depending on the species
8. the unmerchantable bole or top

Table 1. Number and Range of Dimensions for Seven Tree Species

Species	Number	Range of diameters at breast height in inches	Range of total height in feet
White Birch	17	6.0-11.6	47.0-77.5
Red Spruce	25	5.7-14.7	32.0-71.0
Balsam Fir	23	6.2-13.4	41.5-65.0
White Pine	27	5.8-14.6	46.0-79.0
Hemlock	28	5.6-15.1	31.5-61.0
Aspen	14	5.8-9.8	52.5-62.5
Red Maple	20	5.6-15.8	36.5-71.0

Table 2. Weight of Wood Plus Bark Components (in pounds) of Balsam Fir in the University Forest, Stillwater, Maine

	Roots				Branches		Unmer-	Merchant-	
D.B.H.	Small	1-4 in.	4 in. and up	Stump	Small	1 in. and up	chantable top	able bole	Total tree
6.2	16.5	40.0	28.5	22.0	58.5	0.0	39.0	197.0	401.5
6.2	16.0	31.5	7.5	14.5	57.0	2.0	29.0	185.0	342.5
6.4	50.5	33.0	11.5	19.5	54.0	0.0	31.5	257.0	457.0
6.8	42.5	48.0	14.0	12.5	78.0	0.0	40.5	246.5	482.0
7.1	54.0	46.0	32.0	38.0	99.5	0.0	34.5	381.4	855.5
7.4	20.0	21.0	32.0	30.0	67.0	0.0	44.5	379.0	593.5
7.7	34.5	33.0	19.5	31.0	45.5	0.0	42.0	364.0	579.5
7.7	58.5	50.5	19.5	36.5	117.0	0.0	43.5	431.0	756.5
8.3	61.0	91.0	37.0	55.5	113.5	0.0	34.0	443.0	835.0
8.9	67.0	77.5	52.0	38.0	108.5	0.0	127.0	485.5	955.5
9.0	68.5	71.0	49.0	58.5	106.0	0.0	47.0	518.0	918.0
9.3	58.5	53.5	75.0	52.5	83.5	1.0	24.5	553.0	901.5
9.5	33.5	57.0	58.0	32.5	200.5	0.0	27.0	789.0	1197.5
10.1	49.5	64.0	115.5	91.0	208.5	36.5	29.0	726.0	1320.0
10.3	52.5	89.5	80.0	108.5	173.5	19.0	35.5	805.0	1363.5
10.3	70.5	62.5	72.5	64.0	152.5	30.0	27.5	639.5	1119.0
10.6	42.0	76.5	77.0	68.0	199.0	4.0	24.0	743.0	1233.5
10.8	91.0	90.5	100.0	62.0	158.0	66.0	16.5	746.5	1330.5
10.8	67.5	76.0	109.5	58.0	321.5	23.5	27.5	814.5	1498.0
11.9	54.5	112.5	183.0	66.0	330.0	85.0	27.0	1004.0	1862.0
12.0	99.5	98.5	154.5	89.5	191.5	25.0	22.0	901.5	1582.0
12.4	62.5	99.5	159.0	101.0	359.5	57.0	43.0	956.5	1838.0
13.4	108.5	189.0	174.0	141.5	430.0	152.5	52.0	1307.0	2554.5

This was only one of a great many combinations of components that could have been selected. These categories were selected to permit comparison of the currently merchantable bole weight with possible additions above and below the main bole as well as the weight of the small branches and small roots.

After selection the trees were measured at breast height and marked. Each tree was pushed over with a tractor by raising the blade as high as possible and nudging the tree gently a few times. Then the blade was lowered under the exposed roots and the tree completely pushed over. In order to expose all of the roots, the tree was then pushed horizontally a short distance. As a rule about 10 trees were pushed over at one time and this required about one-half hour or less of bulldozer time.

A two-man field party was used for efficiency and safety. For each tree the following procedure was adopted:

1. measure and record total length of tree
2. mark normal stump height and intervals of four feet along the bole until reaching an upper limit of merchantability of four inches
3. remove the earth from the roots with small claw-shaped garden tools
4. sever all roots and rootlets less than one inch with pruning shears and bush-type clippers. Shake them and then rub them vigorously to remove remaining earth before weighing in a basket on platform beam scales capable of weighing 1000 pounds, with individual weighings accurate to one-half pound.
5. A chain saw was used to sever all other components except the branches where an axe was used. The weighing procedures were similar to number 4.
6. The diameter at the small end of each bolt of the merchantable bole was measured prior to weighing. As each bolt was added to the scale the accumulated weight was recorded and the weight of each bolt obtained by subtraction.

Results

Tables 2 and 3 show the weight in pounds of each component of the balsam fir and red maple trees in this study as illustrative of the data of the other species. There are large differences, as would be expected, between the weight of the small branches of the conifers and the weight of the small branches in the hardwood due primarily to the difference in the weight of needles versus leaves. For the other seven components there are differences between species which are fairly small.

Table 3. Weight of Wood Plus Bark Components of Red Maple Trees in the University Forest and in Sebois, Maine

	Roots				Branches		Unmer-	Merchant-	
D.B.H.	Small	1-4 in.	4 in. and up	Stump	Small	1 in. and up	chantable top	able bole	Total tree
5.6	12.5	28.5	none	13.0	56.0	2.0	39.5	223.0	374.5
6.0	8.5	22.0	9.0	19.5	81.0	22.0	43.5	158.5	364.0
6.3	32.0	40.0	7.5	30.0	51.5	15.0	41.0	211.5	428.5
6.6	20.0	37.0	3.5	29.5	57.5	8.5	44.0	348.0	548.0
6.9	44.0	45.0	24.5	34.5	55.5	23.0	59.0	303.0	583.5
7.4	25.5	60.0	40.0	34.5	121.0	21.5	55.0	383.0	740.5
7.9	35.5	53.0	18.5	68.0	89.5	4.5	32.5	418.5	720.0
8.0	29.5	65.0	79.5	84.0	42.0	19.5	37.0	430.0	786.5
8.5	24.5	71.0	58.5	46.5	61.0	47.0	39.0	439.5	787.0
8.6	37.0	73.5	91.0	29.0	75.5	71.5	47.0	535.5	960.0
8.6	49.0	47.5	111.0	111.0	127.0	41.5	50.5	541.0	967.5
9.0	27.5	50.5	24.5	77.5	59.0	15.5	55.0	631.5	941.0
9.7	64.5	122.5	43.0	130.5	155.0	150.0	43.0	939.0	1647.5
10.0	22.0	32.0	105.5	89.0	112.0	115.5	40.0	799.0	1315.0
10.4	49.5	114.0	103.5	87.0	216.0	195.5	41.5	927.0	1734.0
10.8	57.5	117.5	105.5	157.5	128.0	77.5	22.0	869.0	1534.5
10.8	48.0	42.0	30.5	81.5	47.5	74.5	54.5	874.0	1252.5
11.5	66.5	148.0	109.0	116.5	183.5	79.5	68.5	937.5	1709.0
13.2	78.0	239.0	36.5	117.0	109.0	51.0	105.0	1702.5	2438.0
15 8	86.0	18.0	196.5	323.0	120.5	219.5	122.0	2038.0	3123.5

Table 4. A Partial Summary of Results by Species Showing the Relation between Groups of Tree Weight Components for Seven Eastern American Tree Species.

Species	Merchantable bole as % of total tree		Material one inch and larger above and below merchantable bole as % of merchantable bole		Material one inch and larger for entire tree as % of total tree	
	range	average	range	average	range	average
Red Spruce	40-69	53	38-69	50	61-88	80
Red Maple	44-77	60	35-73	47	75-93	88
Balsam Fir	45-66	58	22-84	44	74-86	83
White Pine	54-73	64	23-59	38	83-92	89
Hemlock	37-64	50	35-87	58	69-87	79
White Birch	44-73	61	24-92	44	72-92	88
Aspen	54-65	60	26-69	46	81-91	87
General average (based on actual weights)		57		47		84

Table 4 presents a partial summary of the results by species. There are differences in the ranges and averages for the three sets of comparisons presented. However, the following general statements can be made for all seven species:

1. the present merchantable bole is slightly more than half of the total tree weight

2. The portion of the tree larger than one inch above and below the merchantable bole amounts to almost half the weight of the merchantable bole *with two-thirds of this below* the merchantable bole.
3. The portion of the tree larger than one inch is slightly more than 80% of the total weight of the tree.

Discussion

It is reasonable to question the choice of components into which each tree was divided. As the degree of utilization at a mill increases the harvesting industry will alter its standards. The ultimate lower size limit of woody material that will be used in a mill will depend on machinery limitations, earth and stones, bark and the over-riding economic considerations. In this study a one-inch limit for the roots and branches was arbitrarily selected to contain the data within reasonable limits. The roots were sorted into portions smaller and larger than four inches for convenience in handling. The stump was considered to be the unused base of the bole with the large roots severed almost at right angle to the bole.

At least 2% of the total weight of wood and bark was lost by use of a chain saw. No attempt was made to measure this as the loss applied to trees of all sizes. Any effort to calculate the estimated loss would have been tedious and subject to considerable error in the root sections because of the irregular shapes.

The one and four-inch limits on the roots and branches were visual estimates checked by actual measurements. The branches are quite circular thereby minimizing the human error in visual estimation. However, the roots are seldom circular, so that human judgment was essential and error inevitable. Minor variations in component weight can be attributed to such judgments.

A few roots were lost in the process of pushing the tree over with the tractor. No attempt was made to locate these because the actual quantity appeared to be very small. This was equally true of the small amount of earth left on the small roots and rootlets. Inasmuch as the small roots were of negligible importance in this study, it was not considered worthwhile to take the time and effort to completely remove all of the earth from each root. In order to obtain reliable weights of the wood and bark in the root component, the earth and stones were removed manually which was time-consuming. For large scale operations utilizing the roots it would be necessary to develop equipment that would remove the earth and stones quickly and efficiently. Such equipment might be costly to develop and awkward to manuever in the forest.

tion in advance of the economic considerations that could force us into this position.

Complete tree logging in which maximum use would be made of the entire tree would require the development of new equipment. The components of such complex equipment are already in existence commercially. For many years the destructive distillation process in the southern states has utilized stumps and roots of southern pines. Large chippers have been developed and are used on the west coast to pulverize the tops and branches. A machine called the Utilizer produces chips from long logs and is now being used productively in the state of Washington. A new flakeboard mill of German design in New Brunswick, Canada, is able to utilize small roundwood with bark of virtually any species. The problem would be the efficient combination of these into an economically practical, mobile, self-propelled machine.

The portion of the tree that could not be used even with the new equipment might be chopped into small pieces and returned to the forest floor by a blower. By reducing this material to a comparatively fine state it will be quickly changed to organic matter and become part of the soil.

The forest preservation aspect of this new harvesting procedure would ideally be continued by planting genetically superior trees with mechanical planters to provide the next crop. At the present time in the northeastern states there is an abundance of regeneration with species that have the capacity to survive. To compete with other regions this attribute must be augmented by maximum vigorous growth. This can be accomplished by the large scale production of improved stock developed by forest geneticists.

It is inconceivable that such harvesting and planting would be carried out on rocky ridges or in swamps and bogs, as it is inconceivable to imagine huge wheat combines or mechanical cotton pickers in similar situations. Therefore, greatly increased utilization of the tree and tree planting in the northeastern states would be confined to the appropriate sites and this would be equally true of other regions of the country.

This study was conducted to obtain facts that might indicate the possibility of more intensive utilization of trees selected for harvesting. The potential of new harvesting equipment makes it possible to consider harvesting every standing tree which could materially increase the yield per acre. The twin approach, increased utilization of every felled tree and increasing the number of felled trees per acre, can make it possible for the forest industries to contemplate a reduction in their timberland holdings or an increase in mill production.

The field work established the time requirements to cut, measure and weigh the components of trees. Two men can do all of the work on three trees six inches in diameter or one tree 15 inches in diameter in one working day of about nine hours.

The relative ease of obtaining such data on large forest grown trees makes it possible to consider physiological and ecological studies on other than greenhouse-size trees, and such studies can materially increase our knowledge of tree growth. Knowledge of the whole tree and its components conceivably might improve sample plot analyses to evaluate thinnings or other manipulations of the forest. Similar studies on other coniferous and broadleaf species can affect the general concepts of tree use and growth currently held by foresters and may alter the mensurational approach to yield table preparation.

DRY WEIGHT STUDIES[3]

The fresh weight studies included the bark and moisture, the woody fiber, branchlets, leaves or needles and the rootlets and root hairs at the time the tree was pushed over. Young et al (1965) prepared regression equations from the data on the seven tree species relating fresh weight to tree dimensions. Thus it was possible to compute the fresh weight for the complete tree or groups of components for the several species. For these species white birch was the heaviest and balsam fir the lightest with seldom more than a 20% spread between the extremes.

With considerable variation in bark and moisture content the fresh weight data do not show the actual differences in fiber content among the seven species. As the amount of dry fiber present is critical in the production of pulp, these studies were conducted to obtain information on the oven-dry weight of woody fiber in each of the eight components comprising the complete tree for the seven species.

Methods

Field procedures

To represent each of the seven species (white birch, red spruce, balsam fir, aspen, red maple, white pine and hemlock) a tree approximately eight inches in diameter and 50 feet in total height was selected on the University Forest, Stillwater, Maine in August, 1964. The techniques described by Young et al (1963) were employed to obtain the fresh weight of each component (figure 1). This was accomplished for a single species each morning.

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In order to estimate the moisture, bark, wood, branchlet, rootlet and leaf content of each component, as well as the specific gravity of the woody fiber, samples were immediately selected, sealed in plastic bags and placed in a heavy-duty plastic container for laboratory work as follows:

Sample Designation	Description
1.	A disk between one and two inches in thickness removed from about six inches above the lower end of the butt bolt.
2.	A disk between one and two inches in thickness removed from the center bolt of the merchantable bole. If an even number of bolts, then it was removed from the bolt *below* the middle of the merchantable bole.
3.	A disk between one and two inches in thickness removed from about six inches below the top end of the top bolt of the merchantable bole.
4.	A section between two and four inches in length removed from the center of the unmerchantable bole.
5-A and 5-B	Random samples from the branch portions larger than one inch selected to avoid nodes. Each section three to six inches in length.
B<1″	Three to six branch sections representing material less than one inch in diameter. In the laboratory these were separated into the portion larger than and the portion smaller than one quarter inch to estimate the percentage of each portion.
B2	Sample of B<1″ to estimate percent of moisture in material smaller than one-quarter inch.
B1	Subsample of material larger than one-quarter inch in B<1″ to estimate moisture, bark and wood percentages.
6-A and 6-B	Disks between one and two inches in thickness from the roots larger than four inches in diameter.
7-A and 7-B	Random samples from the roots one to four inches in thickness. Selected to avoid internodes. Each section three to six inches in length.
R<1″	Similar to B<1″
R2	Similar to B2
R1	Similar to B1

Laboratory procedures

The field work described above took about a half day for two men and the laboratory work took the remainder of the day for the same two men. The Penobscot Chemical Fibre Company, Great Works, Maine made its laboratory available for this phase of the study.

TAPPI standard T 18 m-53, "Specific Gravity (Density) and Moisture Content of Pulpwood (Method 1, In Balance)" was followed to determine wood specific gravity and moisture per cent on a dry weight basis.

Analytical procedures

The samples were used to estimate the pounds of wood, bark, moisture, etc. in each of the components of the felled trees by using the following combinations to represent each component:

Component (Figure 1)	Combination of Samples
Merchantable bole	1, 2, 3
Unmerchantable bole	3, 4
Stump	1
Roots larger than four inches	6A, 6B
Roots one to four inches	7A, 7B
Branches larger than one inch	5A, 5B
Branches smaller than one inch	B1, B2, B<1"
Roots smaller than one inch	R1, R2, R<1"

For all components except the small branches and small roots the samples representing the component were added to estimate the percentage of wood, bark, moisture and specific gravity of the component. These percentages were then multiplied by the fresh weight of the component to estimate the wood, bark and moisture in pounds for each component. Two additional sampling steps were necessary for the small branch and small root components. The sample designated as B<1" or R<1" provided information on the relative portions smaller than and larger than one-quarter inch in the component. The sample designated as B2 or R2 provided information on the relative amount of woody fiber in the portion larger than one-quarter inch. The sample designated as B1 or R1 provided information on the bark, wood and moisture of the material larger than one-quarter inch in the small branch or small root components. The combined information from the three samples in each component, small branches and small roots, yield the final results concerning the wood bark, moisture, leaves or needles of the particular component.

Results

Table 5 is typical of the information obtained for each of the 16 sampling units within an individual tree. Bark as a per cent of the

Table 5. Fresh and Dry Weight of Sample Sections from a Single Balsam Fir Tree, University Forest, Stillwater, Maine

Sample designations	Fresh Weight			Dry Weight		Per Cent Bark		Per Cent Moisture on dry wgt. basis		Displacement volume	Specific gravity
	Wood and bark	Wood	Bark	Wood	Bark	Fresh weight basis	Dry weight basis	Wood	Bark		
		*	**								
B<1"	1626	336	1290								
B2	720			243							
B1	18	11	7	6	4	38.8	40.0	83.3	75.0	12	.500
5B	36	27	9	13	4	25.0	23.5	107.7	125.0	30	.433
5A	41	30	11	16	5	26.8	23.8	87.5	120.0	35	.457
4	163	131	32	44	13	19.6	22.8	197.7	146.2	152	.289
3	193	161	32	55	16	16.6	22.5	192.7	100.0	197	.279
2	875	754	121	282	62	13.8	18.0	167.4	95.2	953	2.96
1	524	449	75	192	39	7.4	16.9	133.9	92.3	631	.304
6A	594	486	108	192	53	18.2	21.6	153.1	103.8	593	.324
6B	264	216	48	76	22	18.2	22.4	184.2	118.2	236	.322
7A	77	52	25	16	9	32.5	36.0	225.0	177.8	55	.291
7B	98	76	22	28	12	22.4	30.0	171.4	83.3	77	.364
R1	22	12	10	5	4	45.5	44.4	140.0	150.0	9	.556
R2	136			56							
		*	**								
R<1"	322	174	148								

* Weight of material greater than one-quarter inch
** Weight of material less than one-quarter inch

sample increased from the base of the tree in both directions for balsam fir and this same pattern occurred in the other species. The specific gravity of the small branch and small root components of the other six species was higher than that of balsam fir.

The basic measurements and the total fresh weight of the sample trees are shown in table 6. This table also contains the specific gravity of the three major portions of the tree and the complete tree. The portions below and above the merchantable bole in white birch and red maple have a higher specific gravity than the merchantable bole. The reverse of this is true for balsam fir, hemlock and red spruce. Neither pattern holds for aspen or white pine. In the former the merchantable bole has a lower specific gravity than the portion above the bole but a higher specific gravity than the portion below it. Exactly the reverse situation is true for white pine.

This is entirely inadequate information from which to draw any major conclusions. It would be well to make similar observations in future studies as a means of ascertaining the relationship within and between softwood and hardwood species with regard to the relationship of the specific gravity of the three major portions of a tree.

The per cent of dry fiber, dry bark and moisture in each component of each of the seven species is shown in table 7. For all components balsam fir has either the smallest or almost the smallest percentage of dry fiber with just the reverse true of red maple. Table 8 shows the oven-dry wood as a per cent of the fresh weight of various groups of components and the complete tree. Balsam fir has the least with white pine, hemlock and aspen in a group above it. White birch and red spruce appear in a group above the three previously mentioned species with red maple having the highest percentage of oven-dry wood of the seven species studied.

In the two fresh weight studies the logging residue of material larger than one inch amounted to 47% of the weight of the merchant-

Table 6. Basic Data and Specific Gravity of the Three Major Segments of each of Seven Tree Species.

Species	Dbh. in.	Total ht. feet	Complete fresh wgt. lbs.	Specific Gravity			
				Above bole to 1″	Merch. bole	Below bole to 1″	Entire tree to 1″
White Birch	8.4	61.5	996.5	0.516	0.525	0.507	0.519
Red Maple	7.6	48.5	760.0	0.539	0.581	0.572	0.561
Hemlock	8.1	44.0	789.5	0.422	0.408	0.438	0.422
Red Spruce	7.6	52.0	739.5	0.472	0.435	0.461	0.457
White Pine	8.9	52.0	1010.0	0.352	0.387	0.428	0.408
Aspen	7.7	50.0	622.0	0.381	0.342	0.336	0.341
Balsam Fir	8.2	45.0	848.0	0.309	0.297	0.317	0.309

Table 7. The Percent of Dry Wood, Dry Bark and Moisture in Each Component of the Tree For Seven Species

Species	White Birch			Red Spruce			Red Maple			Balsam Fir			Hemlock			Aspen			White Pine		
Component	Dry wood	Dry bark	Moisture	Dry wood	Dry bark	Moisture	Dry wood	Dry bark	Moisture	Dry wood	Dry bark	Moisture	Dry wood	Dry bark	Moisture	Dry wood	Dry bark	Moisture	Dry wood	Dry bark	Moisture
*Branches less than one inch	12.7	45.0	42.3	8.5	39.4	52.1	16.1	39.8	44.1	6.9	31.4	61.7	9.7	36.4	54.0	9.1	43.1	47.8	13.3	33.5	53.2
Branches larger than one inch	43.5	13.4	43.1	50.0	7.5	42.5	47.6	12.4	40.0	38.5	10.8	50.8	39.7	8.6	51.7	37.1	22.1	40.8	37.5	10.0	52.5
Unmerchantable bole	43.8	11.3	44.9	44.2	10.1	45.7	48.9	9.7	41.4	27.7	8.0	64.3	36.9	6.2	56.9	37.5	14.3	48.2	33.3	6.7	60.0
Merchantable bole	48.3	8.4	43.3	49.8	6.8	43.4	52.9	8.1	39.0	33.2	7.3	59.5	37.7	6.1	56.2	37.6	10.2	52.2	39.9	9.2	50.9
Stump	49.2	7.4	43.4	49.7	6.5	43.8	54.7	7.4	37.9	36.6	10.3	53.2	38.5	6.5	55.0	38.9	10.0	51.1	39.2	10.3	50.5
Roots larger than four inches	48.7	7.9	43.4	43.5	8.0	48.5	52.2	6.1	41.7	31.1	8.6	60.2	39.7	8.6	51.7	33.3	9.1	57.6	40.1	8.5	51.4
Roots one to four inches	45.0	11.2	43.8	43.7	12.5	43.8	42.3	10.5	47.2	25.0	12.0	63.0	39.2	10.8	50.0	25.3	14.0	60.7	33.4	7.6	59.0
*Roots less than one inch	25.2	32.4	42.4	39.7	21.2	39.1	26.8	27.6	45.5	12.3	28.7	59.0	11.1	32.8	56.1	19.4	30.0	50.6	21.0	25.1	54.0

*The entry in the dry wood column is for material in the one quarter to one inch diameter portion.
The entry in the dry bark column includes all material one quarter inch and less such as bark, wood and leaves or needles.

able bole which in turn is about 57% of the weight of the total tree. Table 9 based on oven-dry weight of fiber shows the comparable results as 44 and 71%. It is interesting to note in this same table that the dry wood fiber in the logging residue one-quarter inch to one inch in diameter is 11% of the dry weight of fiber of the merchantable bole. Thus all logging residue including material as small as one-quarter inch in diameter amounts to 55% of the dry weight of the woody fiber in the merchantable stem. The last four columns of table 9 show the logging residue larger and smaller than one-quarter inch in terms of the total dry woody material in the tree either larger than one inch or larger than one-quarter inch in diameter.

Table 8. Dry Wood as a Per Cent of the Fresh Weight of Various Groups of Components for Seven Species of Trees in Maine.

Components	Species						
	White birch	Red spruce	Balsam fir	White pine	Hemlock	Aspen	Red maple
*Complete Tree	41.8	41.0	22.3	35.8	31.0	34.3	46.1
*Large roots up to and including small branches	42.6	40.9	22.5	36.6	31.7	34.5	47.5
Total bole and Total branches	42.0	39.7	21.2	35.9	30.9	34.8	46.5
Total bole	48.0	49.3	32.7	39.7	37.7	37.6	52.5
Merchantable bole	48.3	49.8	33.2	39.9	37.7	37.6	52.9

*Includes oven-dry weight of woody fiber to material as small as one-quarter inch in diameter

Discussion

The sampling scheme employed in this study has not been tested to evaluate its adequacy. A separate and complete study should be conducted to determine the minimum number of samples to satisfactorily describe each component of a tree for trees of different dimensions and for different species. Baskerville (1963) removed one disk from each of the uppermost eleven nodes and one disk every three feet from there to the stump. After 25 trees he reduced sampling to every third section. This is still considerably more than the three samples used to estimate the merchantable bole characteristics in this study.

The triple beam balance that was used had a capacity of twenty kilograms and read to a single gram. This was satisfactory for the large disks that had to be immersed in a pan of water. However, the beam moved slowly so that operator-error could have been introduced in weighing the samples of four to 20 grams. Based on observations made

Table 9. Dry Wood in the Merchantable Bole and in the Logging Residue as a Percentage of Several Groups of Tree Components

Species			Logging Residue (Dry Wood)					
	Dry wood in Merch. Bole as % of total dry wood in material larger than one inch	Dry wood in Merch. Bole as % of dry wood in material larger than one inch	Over 1" as a % of dry wood in Merch. Bole	1/4-1" as a % of dry wood in Merch. Bole	Over 1" as % of dry wood in tree over 1"	1/4-1" as % of dry wood in tree over 1"	Over 1" as % of dry wood in tree over 1/4"	1/4-1" as % of dry wood in tree over 1/4"
White Birch	76.6	71.1	30.6	10.1	23.4	7.7	21.7	7.2
Red Maple	62.0	57.7	61.4	11.9	38.0	7.4	35.4	6.8
Hemlock	75.7	69.5	58.5	11.8	44.3	8.9	40.6	8.2
Red Spruce	66.0	60.9	51.5	12.8	34.0	8.4	31.3	7.8
White Pine	73.5	68.8	36.0	9.4	26.5	6.9	24.8	6.4
Aspen	76.1	73.2	31.4	5.1	23.9	3.9	25.9	3.8
Balsam Fir	67.0	58.3	49.3	8.3	33.0	14.9	28.7	13.0
Average (Based on weight)	71.1	65.8	44.0	11.2	31.3	8.0	29.0	7.4

in this study, a series of weight scales should be used for samples of different sizes to maintain the same relative error in weighing.

In this study, data were only obtained on one tree per species. There is no reason to believe that data from a single tree will accurately depict the fresh weight-dry weight of fiber relationships for all components of trees of different dimensions. It is quite possible that a major study involving several trees from each diameter-height class might yield results showing a differential rate of change in the fresh weight-dry weight of fiber relationship with a change in tree dimensions.

Conclusions

Based on data from one tree per species it appears that:

1. There is a much greater difference in the dry weight of fiber between the components of the seven tree species in Maine than is indicated in the fresh weight differences.
2. Fresh weight of the bole is not an accurate indication of the dry weight of fiber in the bole as a percentage of the dry weight of fiber to a one inch limit.
3. The dry weight of the woody fiber in the material one-quarter inch to one inch in diameter in the roots and branches amounts to 11% of the dry weight of the merchantable bole.
4. The dry wood of the logging residue, including all material down to one-quarter inch in diameter, weighs 55% as much as the dry wood of the merchantable bole. This means that for every 100 tons of dry fiber removed from the forest in the form of the so-called merchantable bole 55 tons of dry fiber in the form of logging residue is left in the forest.

APPLICATION TO A FOREST INVENTORY[4]

An outgrowth of the complete tree concept has been the preparation of preliminary fresh and dry weight tables (Young, Strand and Altenberger, 1964) for red spruce, balsam fir, white pine, hemlock, white birch, red maple and aspen in Maine. These tables are for individual components, groups of components and the complete tree. With these tables it is possible to experiment with weight as a replacement for the cord in the preparation of operating and management plan inventories as well as "scaling" the cut product.

Discussions with foresters of the St. Croix Paper Company, Woodland, Maine and the James W. Sewall Company, Old Town, Maine led to preparation of programs for an IBM 1620 computer (Young and

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Altenberger, 1963) to compile plot and strip inventories directly from the field tally sheets including the statistical error of estimate. As a result of this work some companies have reduced the amount of field sampling and by using the computer their limited professional personnel eliminate tedious office computations and utilize this additional time for other matters.

The Woodlands Division of the St. Croix Paper Company is one of the many industrial users of the IBM 1620 Computer Center of the University of Maine. With their consent two operating inventories that had been analyzed and compiled by the computer were made available for this study. The print-off sheets were compiled by diameter class within species within each type and then summarized by species with all types combined as illustrated by table 11.

Inasmuch as the field data had been key punched on IBM cards and the same program would be used, it was relatively simple to perform the fresh and dry weight analyses of the two inventories. Local fresh and dry weight tables as illustrated in table 10 were individually substituted in the memory of the computer for the cord volume table by Professor Altenberger. At this point, keeping in mind that the genius and skill is entirely in the construction of the computer and the preparation of the program, the appropriate buttons are pushed and a few minutes later the results appear neatly packaged on the print-off sheets.

The two analyses for each operating inventory required a total of two hours of computer time or one-half hour per analysis. The print-off sheets are identical to the cord analysis except that fresh weight or dry weight of fiber has replaced cord volume as illustrated in table 11. For this paper the comparison of fresh weight and dry weight of fiber with cord volume has been limited to the summary by species for all types combined. The weight in pounds has been converted to tons with the results appearing in tables 12a and 12b. These have been analyzed

Table 10 Local Weight Tables for Spruce

Diameter breast	Complete Tree		Merchantable bole	
high in inches	Fresh weight	Dry weight	Fresh weight	Dry weight
6	380	156	200	100
7	560	230	290	145
8	790	324	420	210
9	1080	443	570	285
10	1400	574	750	375
11	1720	705	950	475
12	2130	873	1170	585
13	2560	1050	1430	715
14	3030	1242	1680	840
15	3500	1435	1940	970
16	3970	1628	2220	1110

Table 11. Stand and Stock Tables for Spruce in Type S2C, 7 plots, 98 acres in terms of Fresh Weight, Dry Weight and Cord Volume

Diameter breast high in inches	Total trees in the stand	Trees per acre	Volume in cords for the stand	Volume in cords per acre	Complete tree fresh weight in the stand (lbs.)	Fresh weight per acre in lbs.
6	140	1.429	5.320	0.054	53,200	542.855
7	140	1.429	9.520	0.097	78,400	800.000
8	280	2.857	24.640	0.251	221,200	2,257.145
10	140	1.429	22.680	0.231	196,000	2,000.000
12	210	2.143	55.020	0.561	447,300	4,564.285
15	70	0.714	30.800	0.314	245,000	2,500.000
Total	980	10.000	147.980	1.510	1,241,100	12,664.285

Diameter breast high in inches	Complete Tree		Merchantable bole		Merchantable bole	
	dry weight in the stand in pounds	dry weight per acre in pounds	fresh weight in the stand in pounds	fresh weight per acre in pounds	dry weight in the stand in pounds	dry weight per acre in pounds
6	21,840	222.855	28,000	285.715	14,000	142.855
7	32,200	328.570	40,600	414.285	20,300	207.145
8	90,720	925.715	117,600	1,200.000	58,800	600.000
10	80,360	820.000	105,000	1,071.430	52,500	535.715
12	183,330	1,870.715	245,700	2,507.145	122,850	1,253.570
15	100,450	1,025.000	135,800	1,385.715	67,900	692.855
Total	508,900	5,192.855	672,700	6,864.285	336,350	3,432.145

Table 12a. Summary of Results for Operating Inventory of 1923 acres based on 171 fifth acre circular plots

Species	Volume in cords	Fresh weight—tons		Dry weight of fiber—tons	
		Complete tree	Merchantable bole	Complete tree	Merchantable bole
Spruce	13,181	54,329	29,704	22,280	14,852
Fir	1,405	4,602	2,706	1,013	893
Hemlock	21,355	85,929	44,460	26,639	16,897
White Birch	178	1,059	644	444	309
White Pine	805	3,036	1,783	1,093	713
Hardwoods	4,366	19,842	11,325	9,127	6,002
Totals	41,290 cords	168,797 tons	90,622 tons	60,596 tons	39,666 tons

Table 12b. Summary of Results for Operating Inventory of 1976 acres based on 180 fifth acre circular plots

Species	Volume in cords	Fresh weight—tons		Dry weight of fiber—tons	
		Complete tree	Merchantable bole	Complete tree	Merchantable bole
Spruce	14,000	57,606	31,467	23,623	15,734
Fir	1,195	3,897	2,297	858	758
Hemlock	19,967	79,632	41,279	24,687	15,689
White Birch	363	2,096	1,283	880	616
Hardwoods	4,873	22,142	12,711	10,185	6,736
White Pine	1,207	4,867	2,796	1,753	1,118
Totals	41,605	170,240	91,833	61,986	40,651

in table 13 to show the relationship between the merchantable bole and the complete tree for both fresh and dry weight. This demonstrates that on a dry weight basis the merchantable bole is a larger percent of the total tree than on a fresh height basis.

Table 13. Merchantable Bole and Remainder of Tree as Percentage on a Fresh and Dry Weight Basis with ALL Species Combined by Area

Areas in acres	Fresh Weight Basis: Merchantable bole / complete tree	Fresh Weight Basis: Remainder of tree / merchantable bole	Dry Weight Basis: Merchantable bole / complete tree	Dry Weight Basis: Remainder of tree / merchantable bole
1923	54	86	65	53
1976	54	85	66	52

Weight versus cord scaling

The cord is an ancient unit of measurement which originated with fabric or cord as the measuring device. It appears in John Evelyn's Sylva (1670) as a standard unit of measurement in England. When the population of the temperate climatic zone of the world was small, wood was cheap and relatively little was used in terms of the enormous amount available. As recently as 1914 (Moon and Brown, 1915) only about 4,000,000 cords of pulpwood were used by the pulp and paper industry of the United States demonstrating that this was only a minor forest industry then. Now the annual consumption of pulpwood exceeds 40,000,000 cords, more than a ten-fold increase, and the pulp and paper industry is now a major forest industry. Stumpage, harvesting and transportation costs have increased in the past 50 years. By the time all of the pulpwood is in the mill yards the total cost is in the neighborhood of a billion dollars. With so much involved in each phase of the process of converting the standing tree to pulpwood sticks in the mill yard, there is increased emphasis on the accuracy of wood measurement. The limitations of the cord have been well known for a long time (Graves, 1906). However, it has only been in the past fifteen years or so that methods of improving the accuracy of cord scaling has been given serious attention. Martin (1962) succinctly summarized the situation by stating "There are new concepts required in the wood measurement field and these are the direct result of operating changes brought about by mechanization in the industry."

To satisfy the present requirement for wood measurement accuracy in the pulp and paper industry it is highly desirable that we consider weight as the basic unit of measurement. Weight scaling has become well established at many mills throughout the country where roundwood and chips are weighed on large truck scales. Weight scaling can be extended into the woods by strain gauges and other adaptations that can be added to equipment used to lift wood. In addition to the psychological problems involved in changing from a traditional measurement unit to a new unit there are technical problems that must be solved. There are no conceptional problems apparent. Braathe and Okstad (1964) and Stemsrud (1964) have demonstrated techniques for determination of the moisture content of roundwood on trucks so that this can be extended to the determination of estimated dry weight of wood arriving at the mill.

Acceptance of weight as the primary unit of measurement clarifies the situation for the logger and the pulp maker. Bulldozers, cranes, front end loaders, forklift trucks and the entire gamut of trucks for transportation as used in the process of pulpwood harvesting are rated in terms of pounds. With pulpwood measured by weight there no longer will be any need of estimating the weight of various cord quantities which vary with species, piling and scaling techniques. It should be easier to utilize harvesting and transportation equipment with weight as a common unit. From the standpoint of mill management the use of dry weight in the forest inventory, in harvesting and transportation and in the records of wood delivered to the mill yard should eliminate many of the problems that exist today in internal company management. Lest there by any question of my meaning, I am referring to the long-time argument about wood delivered by woodlands and wood received by the mill, as well as the question of how many cords of wood does it take to make a ton of paper. Tables 12a and 12b show the fresh weight and dry weight inventories of the merchantable stem and the complete tree. The former supplies the framework for harvesting and transportation and the latter is of value to mill management. For both areas note the amount of woody fiber left as logging residue. There are considerable differences between species in terms of fresh weight. This should be taken into consideration in order to obtain optimum use of harvesting and transportation equipment. This can only be accomplished when the weight of the material being handled is known. Such information is available in the weight tables and in the print-off sheets by diameter classes within species. (table 11).

Harvest measurement on a weight basis

In a relative sense the cost of experimental work with harvesting equipment and methods is small compared to the potential benefit within a company and only infinitesmal if many companies share such expense and information.

The possibilities of such experimental work can be illustrated with wheeled skidders. There are a number on the market and there is world-wide interest. The basic questions are (1) the optimum load to be hauled, (2) the efficiency in terms of topography, climatic effects and operator and (3) the comparative efficiency of the commercially available models.

What chance is there to answer those questions where the emphasis is on production? Some information will be obtained, but it is unlikely that the answers would result in minimum cost per cord or per ton of wood harvested and transported to the mill. On the other hand the use of weight criteria in properly designed experiments, which will represent a direct cost, can provide answers in which there can be confidence. Each wheeled skidder has a known maximum weight of logs that it can haul. There is, however, an "optimum" range of weight in terms of maintenance and operating cost. This range should be determined in the initial experimental work. Once this is known various combinations of log dimensions by species can be determined to insure that the optimum load is planned for each trip of the wheeled skidder. The next set of experiments can account for the effect of topography, season of the year and operator efficiency. Upon completion of these two sets of experiments, sound knowledge of the particular wheeled skidder will be available and with such information available it will be possible to compare the different models on the market.

In table 13 it is apparent that present harvesting methods utilize only about 65% of the woody fiber in a tree. The problems that must be solved in order to utilize the complete tree are both psychological and technological. It seems that the aesthetic love of the forest and the academic training that each forester receives results in his feeling that removal of the stump and roots is unclean and sinful. In conjunction with this is the restricted notion that since stumps and roots are removed only for destructive distillation for turpentine that we should not use them to make any other product. From the biological point of view we do not know at this time what site preparation would be necessary after harvesting the complete tree, if there would be any potential increase in erosion, and what genetically superior species should be planted. From the technological point of view there are problems in harvesting, processing and basic scientific information. The sheer size and mass of the mature tree is no longer a formidable obstacle thanks to modern machinery. However, the earth, stones and bark are obstacles that will have to be conquered. It is entirely possible that thorough investigation will indicate that it is not feasible to use the complete tree if fixed minimum limits of the size of material that can be utilized economically are established. Once the material is in the form of small chips or fibers considerable work will be necessary to determine how to reconstitute the material into boards, posts and other products of a size and shape that will be useful.

It is necessary to recognize that complete tree utilization is not an additional procedure to be added to the present system of harvesting, processing and forest management. It will be completely different in all of these aspects requiring a re-evaluation of forestry and the forest industries. It constitutes a great challenge and a great opportunity in the rapidly evolving world of today and tomorrow.

PULPING STUDIES — Andrew J. Chase

Introduction

The pulping of wood is normally done on only one part or section of a tree, the bole. This is true of all pulping processes, chemical, mechanical, or semichemical. There are scattered examples of companies that are utilizing, on a small scale, other portions of the tree, particularly the top section and larger branches. These companies are located in the western part of the United States or Canada where the average size of trees used for wood pulp makes it more feasible to use some of the branches and tree tops in the manufacture of wood pulp.

The use of lumber mill residue by the wood pulp industry is of course a well established and well known fact. It is fairly common practice today for the larger sawmills to chip their waste material and ship it to nearby pulp mills. This is usually a good grade of raw material and is simply combined with the pulp mills' supply of regular pulpwood. The sawdust is used mainly in the production of lower grade papers and paperboards. Thus the complete usage of the tree trunk is economically feasible and established. This is certainly not the case for the other tree parts.

The main reason that only the tree trunk is harvested in pulpwood cutting operations is the difficulty inherent in cutting, handling, and preparing for pulping of the smaller and much less symmetrical portions of the tree. For many years, and to a large extent at present, manual cutting and handling has been the prevailing method. Wood preparation equipment, most particularly debarkers and chippers at the pulp mill, has been built for the purpose of treating wood from the tree trunks, and will not do an effective job on the smaller and more crooked branches and roots.

The recent design and construction of equipment that can effectively harvest and process into chips most parts of a tree points up the growing interest in more complete utilization of this raw material. This subject has been presented in other parts of this paper and will not be discussed further at this point.

In any consideration of the utilization of normally unused parts of trees for wood pulp there are a number of questions to be answered. The most pertinent of these is the potential of the fibers from these tree parts with respect to their use in papermaking. It would be of little use to conserve this raw material for the pulp and paper industry if it could not successfully be used in the paper making process.

This section is concerned with the results of several studies designed to find an answer to the question—what are the properties of pulp made from parts of a tree other than the bole?

Three separate pulping studies were made in the pulp and paper laboratories of the Chemical Engineering Department, Aubert Hall, University of Maine. Each study was a graduate thesis project and has been referred to briefly in earlier parts of this report. The detailed procedure, results and discussion are presented separately for nitric acid pulping of red spruce, sulfite pulping of red spruce, and sulfate pulping of maple and birch.

Nitric Acid Pulping of Red Spruce

The objectives of this study (Kurrle 1963) were to determine the yield and properties of fiber that could be obtained from several parts of red spruce using a nitric acid process of pulping.

The parts of the tree that were pulped were:

the unmerchantable top,
the roots having diameters from one to four inches,
the roots having diameters in excess of four inches,
the branches, and
the bole.

Six red spruce trees in the University Forest were selected and uprooted with a bulldozer so that an adequate sample of the roots could be obtained. The bole wood was taken from the first four foot section above breast height. The entire unmerchantable top from one to four inches in diameter was utilized as were all branch sections over 0.6 inches in diameter.

Preparation of wood for pulping

The tree parts were chipped in the laboratory using a small four-knife Carthage chipper. Knife settings were such as to produce chips ½ to ¾ inches in length (fiber direction). The chips were then screened and hand sorted to remove slivers, knots, and fines or sawdust.

The chips from similar sections of the six trees were mixed and samples of the composite were removed for pulping. None of the wood had been debarked so some bark was included in each of the total of six nitric acid cooks. A determination of the bark to wood ratios in the chips from all tree sections was made and reported in the original thesis but is not included in this paper.

The moisture content of each set of chips was determined and the chips were stored in air-tight containers until the cooks were made.

Cooking and preparation procedure

The cooks were made in a two-gallon digester constructed of Type 316 stainless steel. A two-compartment container inside the digester made it possible to cook two sets of chips simultaneously.

The cooking conditions are shown in table 14. It may be seen that the nitric acid cook is actually a three-stage treatment of relatively short duration and low temperature. The first and second stages are carried

Table 14. Cooking Conditions for Red Spruce, Using Three-Stage Nitric Acid Treatment.

Stage 1 (acid):
- Liquor concentration: 17% nitric acid
- Liquor to wood ratio: 6 to 1
- Maximum temperature: 195°F.
- Maximum pressure: 150 psig.
- Time to maximum temperature: 10 minutes.
- Time at maximum temperature: 115 minutes.
- Total time: 125 minutes.

Stage 2 (alkaline):
- Extraction of chips with 1% sodium hydroxide.
- Temperature: 165°F.
- Time: 20 minutes.
- Both stages of the cook carried out in the digester.

Stage 1 followed by a cold water wash in open digester.

Stage 3 (alkaline):

Extraction of pulp, *after defibering,* with 2% sodium hydroxide.
- Temperature: Approximately 120°F., by direct steaming.
- Time: 20 minutes.

out inside the digester, the first being a cooking or delignification treatment with nitric acid, the second being an extraction of the partially solubilized lignin with sodium hydroxide. The third stage was essentially another alkaline extraction performed at a lower temperature on the cooked pulp after the chips were defibered.

An attempt was made during the first stage of each cook to recover the gaseous effluent from the digester. The gases were absorbed in cold water thus forming dilute nitric acid which could be reused.

The residual liquor that remained at the end of a first stage was, in one case, mixed with fresh nitric acid and the mixture used to make a cook. The chemicals used in nitric acid pulping make the process almost prohibitively expensive, hence the purpose of the aforementioned recovery and reuse of liquor was solely one of economy of cooking chemicals. The recovery aspects of this work are discussed in some detail in the original thesis and will not be repeated here.

Following the third stage the pulp was thoroughly washed and stored in polyethylene bags. From a determination of the weight of pulp and its moisture content the cooking yield was calculated. The results are shown in table 15.

Table 15. Yield Results for Red Spruce Pulps (Nitric Acid Process)*

Tree part	Acceptable pulp (% of wood cooked)	Rejected pulp (% of wood cooked)
Roots (1" to 4")	37	4
Roots (greater than 4")	38	4
Bole	38	4
Branches	29	11
Top	39	3

*Averages of results from two cooks on each tree part.

In general the yields are relatively low. In the more common acid pulping processes such as the sulfite process cook yields are normally in the 42 to 47% range. Here the figure for all parts of the tree except the branches was approximately 38%. This indicates that the wood was over-cooked with resultant loss of some of the cellulosic material that would not be removed under commercial cooking conditions. The branches were cooked to an abnormally low yield of acceptable pulp. It is possible, however, that the branches may actually have been delignified less than the other tree parts as indicated by the very high percentage (11%) of pulp rejected during the screening process. If the sums of the percentages of accepted and rejected pulp are calculated it is seen that all parts of the tree give total yields that are nearly the same, 40 to 42%

Chemical and physical properties of the pulps

Only one chemical test, the Permanganate Number, was made on the pulps. This test (TAPPI 214) is used to indicate the degree of cooking or extent of delignification of wood pulp. Normal chemical pulps will have permanganate numbers in the range 10 to 20, depending on the process by which the wood was pulped. Examination of the values for this study, table 16, indicates that these pulps were overcooked, hence well delignified and relatively pure in carbohydrate content. The branches were somewhat less delignified but it cannot be said that they were under cooked. Permanganate numbers in the 4 to 6 range may be considered very low, and very uncommon in commercial pulping.

Each different pulp was evaluated for physical characteristics by using the TAPPI Standard Beater Test (T214). This test involves treating a specified weight of pulp under carefully controlled conditions

Table 16. Chemical Properties of Red Spruce Pulps (Nitric Acid Process)

Tree part	Permanganate Number	
	First test	Second test
Roots (1" to 4")	4.6	4.1
Roots (greater than 4")	4.5	4.6
Bole	4.5	4.9
Branches	6.0	5.5
Top	4.0	4.2

in a standard laboratory beater. This is a physical treatment of the pulp which alters such macroscopic features of the fibers as their length, void volume, and cross sectional shape, by cutting, crushing, and maceration. At specified intervals during the beating, samples were removed from the beater and made into handsheets using a standardized procedure (T205). These sheets were conditioned for several days and then tested under the same conditions, 72°F. and 50% relative humidity (T220).

A portion of each pulp sample taken during the beating treatment was also tested for freeness using a standard procedure (T227). This test gives an indication of the drainage characteristics of a pulp, i.e., the rate at which water will drain from and through a pad of the pulp. It also indicates indirectly the degree of pulp strength development resulting from the beating operation. As beating proceeds the freeness decreases, i.e., drainage of water from the pulp is slower and the strength of paper made from the pulp increases. If beating is carried too far, strength will reach a maximum and then decrease as a result of excessive physical damage to the fibers.

The results of freeness measurements and physical tests made on the handsheets are shown in table 17.

Further evidence of the extreme degree to which the wood had been cooked is the rapid decrease in freeness as the pulp was beaten. Normally, a softwood pulp produced by an acid process will require a half hour or more to reach the freenesses attained here in ten minutes.

All components of the tree showed significant strength changes with beating. The decrease in bulk and tear strength and the increase in tensile and burst strength are typical effects.

Table 17 Physical Properties of Red Spruce Pulps (Nitric Acid Process)

Property*	Roots (1" to 4")	Roots (4"+)	Bole	Branches	Top
Freeness 0 min.	636	642	645	419	586
10 min.	330	334	—	224	323
Bulk (cc/gm.)	1.98	2.46	1.98	1.77	2.24
	1.77	1.76	1.70	1.52	1.76
Tensile Strength	3690	2830	2470	3880	3620
	4850	6100	4080	5280	5280
Burst Factor	18	16	25	23	22
	26	32	39	27	37
Tear Factor	42	66	34	33	48
	34	37	36	31	36

* Each property shown for unbeaten pulp and for pulp beaten 10 minutes.

Pulp from the branches might have appeared, before beating, to be quite different from the pulps of other components. The freeness and bulk were significantly lower in the unbeaten condition for the branch pulp. However, there did not appear to be any one pulp that had any consistent strength advantage over the others.

Table 18 contains the results of two optical tests, opacity and brightness.

Table 18. Optical Characteristics of Red Spruce Pulps (Nitric Acid Process)

Property	Roots (1" to 4")	Roots (4"+)	Bole	Branches	Top
Opacity 0 min.	78	83	81	83	83
10 min.	74	68	68	78	74
Brightness	46	49	40	34	46
	43	41	34	31	40

Opacity decreases as a pulp is beaten because paper made of beaten pulp exhibits a greater degree of interfiber bonding, hence less surface within the sheet for reflection and scattering of light. More of the incident light passes through the sheet and it is more transparent.

The unbleached brightness of a pulp is some indication of the degree of cooking or purity. Generally the higher the degree of cooking the higher is the unbleached brightness. There are exceptions to this generality. In fact, over-cooking a pulp can adversely affect its brightness. The brightness values shown in table 18 are quite low for pulp produced by an acid process. This may be further evidence of some over-cooking in this particular study.

It is concluded that the pulps produced by the nitric acid process under the specific conditions employed in this study, are somewhat inferior in physical properties to those produced by the more common acid sulfite processes.

More pertinent to the objective of this study, however, is the fact that the pulps from the normally unmerchantable tree components, tree top, branches, and roots compared very favorably with the pulp from the tree bole.

SULFITE PULPING OF RED SPRUCE

The purpose of this study (Keniston 1964) was similar to that of the work described in the previous section. The same kind of wood, red spruce, was used. A study was made of the physical and chemical characteristics of wood pulps made from the bole, top, roots, and branches, to determine their papermaking qualities. All root portions and branch portions having diameters greater than one inch were used.

The spruce tree was selected in the University Forest, pushed over with a tractor, and the four parts collected for pulping.

The wood was debarked and chipped in the laboratory chipper. The chips were screened and the chipping yield determined.

The four component parts were then cooked in a stainless steel laboratory digester larger than the one used in the work described in the previous section. By using a stainless steel compartment basket inside the digester it was possible to cook all components simultaneously.

An ammonia-base sulfite cook was made and the resulting pulps were evaluated for various chemical and physical properties.

There were very definite differences exhibited by the pulps from the four portions of the spruce trees. Pulps from the top, bole, and roots exhibited very good cook yields and were of good quality with respect to their physical characteristics. The pulp from branches, being composed of much smaller fibers, was inferior in strength properties and was rather low in yield.

Preparation of wood for pulping

This part of the study was similar in most details to its analog in the previous section. The main differences were that the roots were treated in two size categories, and all wood from all tree parts was debarked before being chipped.

Some information was obtained on chipping yield and is shown in table 19. "Rejected chips" was material from the chipper that was under ¼ inches or over ¾ inches in length. The highest percentage of such material was produced from the branch portion and the next highest from the root portion. The reason for the high percentage of rejects is the generally small size and the crookedness of these portions of the tree, and the fact that standard pulpwood chippers are not designed to handle such material efficiently. There was much good wood in this rejected material which would be processed under commercial wood preparation and pulping conditions. The comparison of chipping yields is shown here simply to present the fact that this problem does exist.

Table 19. Yield Results for Pulping Red Spruce (Sulfite Process)

Operation	Roots	Bole	Branches	Top
Chipping:*				
% Acceptable chips	47.2	70.5	23.2	57.8
% Rejected chips	52.8	29.5	76 8	42.2
Cooking:**				
% Acceptable pulp	40.2	42.6	31.5	47.2
% Rejected pulp	3.6	1.9	11.7	1.7
Total cook yield	43.8	44.5	43.2	48.9

*Chipping yield based on weight of wood charged to chipper.
**Cooking yield based on weight of dry chips charged to digester.

Cooking preparation and procedure

The cooking conditions are shown in table 20. This was a normal ammonia-base sulfite cook carried out for a total time of 6¼ hours at a maximum temperature of 285°F. An impregnation time of two hours (time to reach maximum temperature) was used.

Table 20. Cocking Conditions for Red Spruce, Using Sulfite—Ammonia Base

Cooking liquor:	6% total SO_2 1% mill combined SO_2 5% mill free SO_2
Liquor to wood ratio:	6 to 1
Time-temperature cycle:	
Total time, 6¼ hours	
Impregnation time, 2 hours	
Time at maximum temperature, 4¼ hours	
Maximum temperature:	285°F.
Wood charged to digester:	4 pounds from each part of tree, each batch in separate compartment of digester. Total, 16 pounds

Four pounds of each tree part were cooked, each part being contained in an individual section of a compartmented basket. Thus, all parts were treated under similar conditions of time, temperature, pressure, and cooking liquor composition.

At the end of the cook the digester was relieved to atmospheric pressure, and some washing of the cooked chips was done in the digester. They were than removed, in the basket, from the digester and each of the four parts was processed separately through the washing, defibering and pulp screening operations. The amount of acceptable and rejected pulp from the screening operation was used to calculate cook yield figures, total, accepted pulp, and screen rejects (table 19).

With the exception of the branches, the yield of acceptable pulp from this cook was high enough to be encouraging. The top portion gave a particularly good yield of 47%. Although total yield of the branches was good there was a large proportion of reject material in this pulp, indicating that it may have been undercooked. It is known that the compression wood so prevalent in the branches of conifers is more difficult to cook than wood from other locations in the tree.

Chemical and physical properties of the pulps

Table 21 shows results of chemical tests made on the four pulp samples.

Table 21. Chemical Properties of Red Spruce Pulps (Sulfite Process)

Property	Roots	Bole	Branches	Top
Permanganate Number	7.6	13.2	22.9	6.6
Ash Content (%)	0.24	0.36	0.63	0.27
Caustic Solubility (%)	5.54	6.72	7.95	7.86

The permanganate number has been described previously. Based on the values for this test as shown in table 21 it is reasonable to conclude that the roots, bole, and top were well cooked but not overcooked, and this is also substantiated by the small percentage of screen rejects for these three tree parts (table 19). However, the permanganate number for the branch pulp is very high for a sulfite pulp, indicating an undercooked material.

Ash content is simply a measure of the inorganic material in the pulp. Normally it ranges from 0.1 to 1.0 per cent in unbleached sulfite pulps, so all four pulps were normal in this respect.

The caustic solubility determination was made by a standard procedure using an 18% sodium hydroxide solution and a temperature of 20°C (T235). The results of this test simply show the per cent of the pulp that is soluble in an 18% caustic solution at 20°C. and should not be interpreted as being related to alpha-cellulose content. The test may give an *indication* of the relative amounts of hemicellulosic or even the short-chain cellulosic materials in the different pulps. In any event the differences in this property among the four pulps are quite small, with the root pulp showing some exception to this statement.

Table 22 includes the results of fiber measurements. Fiber lengths were determined by projecting the enlarged image of a slide of fibers onto a blackboard and measuring the outline of the fibers. Knowing the magnification of the projector it was a simple matter to calculate the fiber lengths. Several hundred fibers from each of the four pulps were measured and the length values shown in table 22 are simple arithmetic averages of these measurements. Fiber diameters were measured using a microscope and an eyepiece with a calibrated scale. Again, several hundred measurements were made (at the widest cross-section of the fibers) and the arithmetic average is shown.

The distinct difference between the fibers from the branches and those from the other tree parts is evident. Photomicrographs were also made of the fibers and it could be seen that those from the roots, bole, and top were very similar in appearance as well as in dimensions. However, the branch fibers had more the appearance of hardwood fibers, being relatively short, narrow, and pointed at the ends.

Table 22. Fiber Dimensions of Red Spruce Pulps (Sulfite Process)

Part of tree	Fiber length (mm)	Fiber diameter (mm)
Roots	2.11	.021
Bole	2.05	.023
Branches	1.14	.014
Top	2.08	.023

Standard beater tests were made, freenesses measured, and handsheets were tested for strength and optical properties. The results are shown in tables 23 and 24.

Table 23. Optical Properties of Red Spruce Pulps (Sulfite Process)

Property		Roots	Bole	Branches	Top
Opacity	0 min.	82.1	88.7	97.7	82.1
	30 min.	63.8	72.2	89.4	63.1
Brightness	0 min.	54.1	38.9	32.7	57.9

The pulps from all four tree parts responded quite similarly to the beating treatment as shown by the freeness change over a 30 minute beating time. The branch pulp had a slightly lower unbeaten freeness than did the other pulps because of its smaller fibers. Actually, the freeness of the branch pulp *decreased* more rapidly than the freeness of the other pulps during the first 20 or 25 minutes. This is not evident in

Table 24. Physical Properties of Red Spruce Pulps (Sulfite Process)

Property		Roots	Bole	Branches	Top
Freeness	0 min.	700	691	665	690
	30 min.	242	230	265	234
Bulk (cc/gm)		1.38	1.41	1.67	1.34
		1.15	1.13	1.14	1.15
Breaking Length (meters)		8065	7860	3930	7925
		10430	10305	5945	9600
Burst Factor		46	46	23	47
		65	62	31	68
Tear Factor		73	71	42	64
		54	56	21	53
Fold Strength (Double Folds)		318	77	7	194
		978	515	21	504

table 24 because the freenesses for times between zero and 30 minutes are not shown. The more rapid freeness drop for the branch pulp is good evidence of the inherent weakness of the fibers in this section of the tree.

The strength properties of pulp from the roots and top compared very favorably with, and were in some cases superior to, the bole pulp. Strength development for all three of these pulps reached a maximum within the beating time range of 30 to 40 minutes. The inferior physical characteristics of the branch pulp are obvious by comparison.

The low brightness of the branch pulp (table 23) is explainable in terms of the degree of cooking of this component and its relatively high permanganate number. The low brightness of the bole pulp does not seem to be a logical result considering that it was well cooked. A discrepancy in measurement must be assumed here.

Opacities for the various pulps behaved as might be expected. The branch pulp formed a very weak sheet with a low degree of interfiber bonding, as evidenced by the inferior strength properties, and consequently the sheet was very opaque. The other three pulps responded in a normal fashion, with respect to opacity, as they were beaten. The opacity decreases of 15 to 20 points over a 30 minute beating period are typical of a good grade of sulfite pulp.

This study showed rather conclusively that a good grade of pulp can be produced from the root and unmerchantable top sections of red spruce, using the sulfite process of cooking. Cooking yields of acceptable pulp from these tree sections compare favorably with that from the bole section. Pulp from the branches is inferior to the other pulps in nearly all respects, yield, physical properties and optical characteristics.

SULFATE PULPING OF MAPLE AND BIRCH

This pulping study (Michaud and Smith 1964) was made on two types of deciduous trees, red maple (Acer rubrum) and white birch (Betula papyrifera). The deciduous or hardwood species are used extensively as a raw material for wood pulp. They are commonly pulped by the sulfate process or by any of several semichemical pulping processes. Since the sulfate process is the most common industrial method of pulping hardwoods, particularly in New England, it was selected for this study.

The main objective here was the same as that specified in the two previous sections, namely, to determine the yields and properties of pulps from parts of the tree that are being left to waste by present pulpwood operations. In this study the bole, the branches and roots, in excess of one inch diameter, were pulped.

The trees were obtained from the University Forest. Chipping, chip screening and cooking were all done with the equipment described in the previous section.

Preparation of wood for pulping

The various parts of the trees were debarked and chipped separately using a chipper knife setting that would produce ¾ inch chips predominantly. The chips were screened carefully and the accepts and rejects were weighed to determine chipping yield (table 25).

Similar to previous chipping results there were large percentages of reject chips from the roots and branches. The reasons for this have been explained previously.

Table 25. Yield Results for Red Maple and White Birch Pulps. (Sulfate Process)

Operation	Birch			Maple		
	Roots	Bole	Branches	Roots	Bole	Branches
Chipping:*						
% Acceptable chips	32.4	75.2	44.6	52.4	80.9	50.2
% Rejected chips	67.6	24.8	55.4	47.6	19.1	49.8
Cooking**						
% Acceptable pulp ***	45.1	46.2	47.8	36.4	49.8	48.2

*Chipping yield based on wood charged to chipper.

**Cooking yield based on weight of dry chips charged to digester.

***Negligible amount of rejected pulp.

The chips, each different sample stored in a separate plastic bag, were thoroughly saturated with water before being cooked.

Cooking preparation and procedure

Table 26 shows the cooking liquor composition and the cooking schedule.

Table 26. Cooking Conditions for Red Maple and White Birch (Alkaline Sulfate)

Cooking liquor:	
Total chemical: 20.2 gm/liter active alkali	
Sulfidity: 30%	
Chemical to wood ratio:	0.2
Liquor to wood ratio:	10.3 to 1.
Time-temperature cycle:	
Total time: 4½ hours	
Impregnation time: 2¼ hours	
Time at maximum temperature: 2¼ hours.	
Maximum temperature: 340°F.	
Final liquor (black): 5.1 gm/liter active alkali.	
Wood charged to digester: 15.4 pounds.	

The chips were placed in the compartmented basket inside the laboratory digester, each portion in a separate compartment. A total weight of 15.4 pounds was charged. The cooking liquor was then added in the amount required to give the desired chemical to wood ratio of 0.2. It was necessary to add some water to ensure that all the chips were covered with liquor. The net result was a liquor to wood ratio of 10.3 to one, and an initial liquor concentration of 20.2 gm. of active alkali (as Na_2O) per liter.

At the end of the 4½ hour cook the digester pressure was reduced, the pulp was washed in place and then removed into screen boxes. It was then transferred to the Morden Slush Maker where it was defibered. Pulp screening was done on the Bird Vibratory Screen.

The chips had been very thoroughly cooked and there was a negligible amount of screening rejects. Therefore the screened yield and the cook yield are the same, and they are shown in table 25. Yields of 45 to 50% are typical in sulfate pulping and the only pulp not meeting that specification is that from the maple roots.

Chemical and physical properties of the pulps

Permanganate Number and 18% Caustic Solubility tests were made on the six pulps, table 27. The results of the first show that all pulps were cooked to about the same degree, having quite similar permanganate numbers. It is also evident that all the pulps were well cooked. The relatively low permanganate numbers and the fact that there were no screening rejects might indicate that the pulps were overcooked. Subsequent tests for physical properties show that this was not the case.

Caustic solubilities are higher in general than they were for the red spruce pulps with sulfite pulping. This is as it should be inasmuch as the deciduous woods contain higher percentages of the lower molecular weight carbohydrates.

Table 27. Chemical Properties of Red Maple and White Birch Pulps (Sulfate Process)

	Birch			Maple		
Property	Roots	Bole	Branches	Roots	Bole	Branches
Permanganate Number	10.2	10.4	10.9	11.2	9.8	9.9
Caustic Solubility (%)	6.98	8.62	9.75	8.87	8.74	8.35

Standard beater tests were made, freenesses measured, and handsheets made and tested. The results for unbeaten pulp and for pulp beaten 30 minutes are presented in table 28. Some general observations can be made concerning these results.

Table 28. Physical Properties of Red Maple and White Birch Pulps (Sulfate Process)

	Birch			Maple		
Property	Roots	Bole	Branches	Roots	Bole	Branches
Freeness, 0 min.	722	682	623	541	571	584
30 min.	389	244	238	299	342	311
Bulk (cc/gm)	1.67	1.60	1.63	1.45	1.51	1.63
	1.33	1.30	1.30	1.17	1.26	1.28
Breaking Length (meters)	3650	4680	5125	4340	5940	4780
	11875	12000	11645	7480	9375	9255
Burst Factor	22	28	28	32	35	25
	96	97	99	64	81	76
Tear Factor	88	102	70	66	74	67
	108	90	86	74	86	91

Pulp from the maple tree parts had lower freenesses in the unbeaten condition than that from the birch tree. It also beat somewhat slower over the 30 minute period so that at the end of this time the freenesses of the maple bole and branch pulps were higher than those for the corresponding birch pulps.

The birch pulps before beating were generally somewhat weaker and produced a bulkier sheet than the maple pulps. However they did develop strength faster than did the maple pulps with beating and therefore produced stronger, but still bulkier, sheets after 30 minutes of beating.

The strength levels for all pulps with the possible exception of that from the maple roots were unusually high. Hardwood pulps, even those produced by the sulfate process, are not noted particularly for their strength characteristics, but in this case some of the properties, especially burst and tensile, are comparable with those realized in softwood pulps.

Fiber dimensions were measured by the methods described previously and the results are presented in table 29. Two qualities that were not determined in the first studies, lumen diameter and fiber flexibility, were measured and are included here. Lumen diameter was determined, using the microscope and an eyepiece with calibrated scale. Fiber flexibility is a derived quality, being the ratio of lumen diameter to fiber diameter. The birch fibers were nearly twice as long as the maple fibers but were slightly slimmer. Lumen diameters showed no trend in a comparison among pulps from the different trees. For each tree species the value for each of the three dimensions, fiber length, fiber diameter and lumen diameter, decreases with the tree component in the order, roots, bole, branches. As usual there is one exception, the fiber length of the maple root fibers.

The maple fibers being shorter produced the weaker pulps. The fiber flexibility ratio was also lower for these fibers and according to the work of other investigators (Wangaard 1962) the burst and tensile strengths are directly related to this ratio.

Table 29. Fiber Dimensions of Red Maple and White Birch Pulps (Sulfate Process)

Dimension	Birch			Maple		
	Roots	Bole	Branches	Roots	Bole	Branches
Length (mm)	1.00	1.07	0.89	0.51	0.66	0.53
Diameter (mm)	.014	.011	.009	.017	.013	.010
Lumen Diameter (mm)	.0089	.0069	.0055	.0094	.0069	.0046
Fiber Flexibility (Lumen Diam.) (100) / (Fiber Diameter)	62	62	61	57	53	45

In any discussion of correlations or relationships between fiber dimensions and strength properties it should be noted that the fiber dimensions shown here are for the *unbeaten* fibers and considerable change in these qualities probably occurs during the beating operation. Length is shortened, diameter is changed by crushing, bruising, and splitting of the fiber walls, and lumen diameter certainly changes drastically when a fiber collapses.

The results presented show that normal yields of good quality hardwood pulp can be produced from the root and branch portions of red maple and white birch trees using the sulfate pulping process.

POTENTIAL YIELDS OF PULP ASSUMING WHOLE TREE PULPING

Table 30 shows the results of calculations of the potential percentage increases in yields of acceptable pulp from a tree if whole tree harvesting and pulping practices were used. The use of the term "whole tree" is not fully warranted here because the calculations are based on the parts of the tree used for pulp *in these studies,* and in no case were all the tree components used. If they had been it is safe to expect the potential yields would have been higher than these calculations indicate.

Table 30. Possible Pulp Yields of a Theoretical 1000-Lb. Tree

Pulp source	% of total tree weight	BD wood wgt. (#)	Acceptable chip yield (%)	BD chip wgt. (#)	Screened cook yield (%)	BD pulp wgt. (#)	% of original wood wgt.
Maple Bole	55	550	80.9	450	49.8	224	41
Maple Branches	8	80	50.2	40	48.2	20	25
Maple Roots	20	200	52.4	105	36.4	38	19
Birch Bole	55	550	75.7	415	46.2	192	35
Birch Branches	8	80	44.6	36	47 8	17	21
Birch Roots	20	200	32.4	65	45.1	29	14

Maple: Pulp from bole = 224#
Pulp from branches and roots = 58#
$\% \text{ Increase in yield} = \frac{58}{224} \times 100 = 25.9$

Birch: Pulp from bole = 192#
Pulp from branches and roots = 46#
$\% \text{ Increase in yield} = \frac{46}{192} \times 100 = 24.0$

The data in the first column of table 30 are from a study by Young (1963).

A potential increase of about 25% in the amount of useable pulp from red maple or white birch is indicated. Under commercial conditions of wood preparation and pulping the increase would be greater.

SUMMARY OF PULPING STUDIES

Three separate studies were made to determine the yield and quality of wood pulp obtained from those parts of the tree that are normally left in the forest as waste.

A nitric acid process and the ammonium bisulfite process were used to pulp the roots, bole, branches and tops of red spruce. The sulfate process was used to pulp the roots, bole, and branches of red maple and white birch.

The nitric acid process being an uncommon process, not well-established or widely used, produced results which indicated that the pulp from the normally unused parts of the tree compared favorably in strength characteristics with that from the tree bole. The exception to this was pulp from the branches, which was quite inferior in both yield and strength properties.

The study using the ammonium bisulfite process produced results in general agreement with those from the nitric acid process. There was some improvement in yields, particularly from the bole and top sections, and stronger pulps were produced.

Sufate pulping of the red maple and white birch resulted in pulps of very good quality and strength from all the tree parts. Cooking yields were in line with those obtained under commercial pulping conditions.

Approximate calculations based on the cooking yields for each tree component and the weight composition of a tree in terms of the several tree parts indicate that a minimum increase of good pulp amounting to 25% can be realized by utilizing parts normally wasted. Development of wood preparation equipment for processing the smaller parts such as branches and roots would minimize the waste that is produced in the chipping operation and would improve even more the potential yield of pulp from any "whole tree."

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