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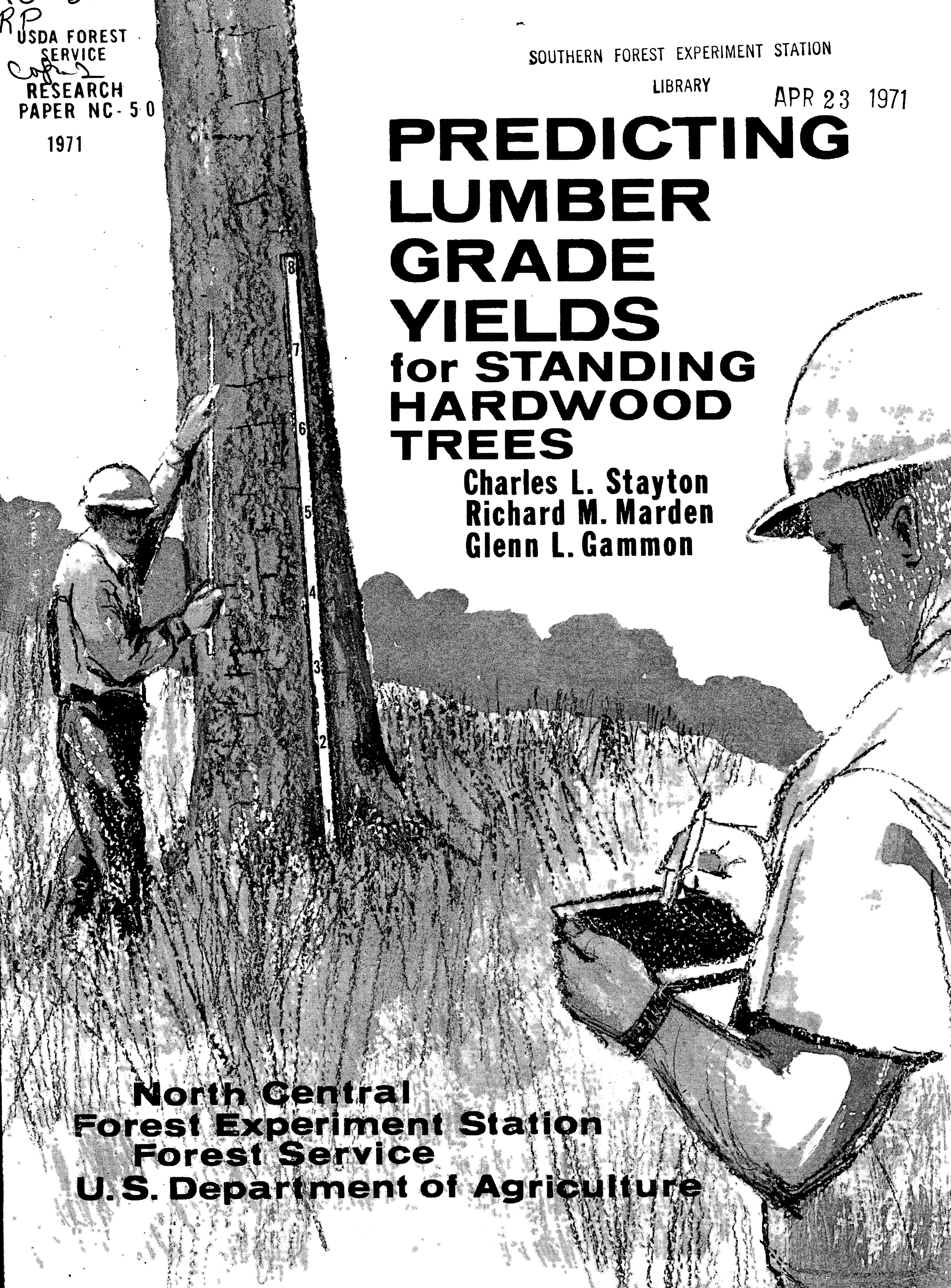
Charles L. Stayton
Richard M. Marden
Glenn L. Gammon



North Central
Forest Experiment Station
Forest Service
U.S. Department of Agriculture

Charles L. Stayton, an Associate Wood Technologist for the Station at the time this report was written, is now an Area Forestry Specialist (Wood Products) for Texas A & M University, Overton, Texas. Richard M. Marden is a Principal Wood Technologist for the Station and is headquartered in their Duluth, Minnesota, office, which is maintained in cooperation with the University of Minnesota-Duluth. Glenn L. Gammon is a Research Forest Products Technologist for the Northeastern Forest Experiment Station and is headquartered in their Columbus, Ohio, office.

North Central Forest Experiment Station
Forest Service — U.S. Department of Agriculture
Folwell Avenue
St. Paul, Minnesota 55101

Predicting Lumber Grade Yields For Standing Hardwood Trees

Charles L. Stayton, Richard M. Marden, and Glenn L. Gammon

Methods of assessing product yields for standing timber are needed to determine the quantity and quality of the timber resource in many areas. This information will indicate where new industries can be located and how much timber is economically operable to existing industries. Accurate timber resource information will assist in development of forest management, timber production, manufacturing, and marketing techniques to meet the increased demand for forest products.

To meet the goals outlined above, we developed a method to assess the quality of standing hardwood sawtimber. Tree stem characteristics were used to predict lumber grade yields for standing sugar maple trees. This paper is an extension of earlier work (Marden 1965), which presented the methodology for developing continuous prediction equations for estimating product yields in standing trees.

SAMPLE DESCRIPTION

Data were collected from sugar maple trees in old-growth northern hardwood stands in Upper Michigan. The trees were selected on the basis of d.b.h. and the number of clear faces within the butt one-quarter of the merchantable[1] stem. Trees were separated into three d.b.h. classes, and three quality classes within each d.b.h. class. The d.b.h. classes were 11-15 inches, 16-20 inches, and 21-26 inches; the quality classes were 0-1 clear faces, 2 clear faces, and 3-4 clear faces. There were 10 trees in each d.b.h. quality class combination, for a total of 90 trees. Tree age ranged from 92 to 289 years, and tree growth rate from 6 to 23 rings per inch of diameter.

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[1] *The merchantable height was restricted by a 6-inch d.i.b. minimum top or separation of stem into two or more distinct branches.*

PREVIOUS WORK

Originally this study was designed to develop prediction equations for estimating clearcutting yields in standing sugar maple trees (Marden 1965). The 90 trees were bucked into 8-foot lengths, which were sawed through-and-through into 1-inch-thick flitches. The flitches were photographed, projected on a screen, and clearcutting yields measured. The clearcutting yields were then related to stem characteristics. Lumber grade yields were not obtained.

Recent publications (Dunmire and Englerth 1967, Englerth and Schumann 1969, Schumann and Englerth 1967) give yields of random-width and specific-width dimension from 4/4 hard maple lumber. Thus, it was obvious that equations were needed to predict lumber grade yields from standing trees. Therefore, we calculated lumber grade yields for each sample tree, using Research Paper FPL-63, "Hardwood Log Grades for Standard Lumber" (Vaughan *et al.* 1966), developed prediction equations, and tested their accuracy. The testing was done by comparing the predicted with the observed lumber grade yields for additional sugar maple trees cut from four different National Forests.

CALCULATING LUMBER GRADE YIELDS

Because our 90 trees had been bucked into 8-foot logs, we had to paper-diagram the merchantable stem length of each tree to permit simulated bucking and log grading according to Research Paper FPL-63. All four merchantable stem faces were drawn to scale on paper, showing defect locations and sizes. This task was relatively easy because all surface abnormalities found on each log had been identified and measured, and all log faces and ends photographed in color.

The board-foot volume for each paper-diagram-graded log of each tree was obtained using the Scribner Decimal C Log Rule. Sound and unsound cull volumes for each log had been measured for another study (Stayton and Marden 1970), and were deducted from the gross volumes. Overrun was accounted for as given in Research Paper FPL-63. Thus, the net mill tally (bd. ft.) was obtained for each log of all 90 trees. Tables 10, 11, and 12 from Research Paper FPL-63 were then used to calculate lumber yields by grade for each log, and log yields were summed to get total yields per tree. These yields, by grade, were used as dependent variables.

INDEPENDENT VARIABLE SELECTION

The independent variables related to clear-cutting yields had been selected earlier (Marden 1965). These variables now had to be tested for predicting lumber grade yields. A defect analysis helped to improve two of the selected independent variables; to determine the stem section that should be used to measure them, the optimum grading section was studied and selected.

Defect Analysis

Tree surface abnormalities, such as knots, bumps, and seams, are related to product yields in standing trees. Therefore, we wanted to know more about relationships between these exterior defect indicators and their associated interior defects.

From a precise study (Stayton *et al.* 1970) we found how often defect indicators had underlying defects in the quality zone.[2] Also, we found that size of the defect indicator (except flutes) was not related to associated interior defect. Therefore, instead of using the size of defect indicators as an independent variable, such defects were now only counted. The percentages of these exterior defect indicators that had interior defects were then applied:

[2] *The quality zone was the portion outside of a core that had a diameter equal to one-half the diameter of the tree at that point.*

X_5 = Number of knots, bumps, and surface rises + 0.62 (number of bark distortions + number of adventitious buds and/or epicormic branches) divided by merchantable stem length.

Because the percentage of flutes with underlying defect increased with increasing flute length, this defect was measured as before. We also continued to measure length of open and overgrown seams, because these defect indicators are often long enough to affect several logs. The percentages of flutes and seams that had associated interior defect were then applied to their total length measurements:

X_6 = Total length of open seams + 0.67 (total length of overgrown seams) + 0.49 (total length of flutes) divided by merchantable stem length.

Optimum Grading Section

Counting or measuring defect indicators to calculate X_5 and X_6 should be restricted to a portion of the stem (optimum grading section) between 0 and 16 feet. Obviously, the most desirable section is that nearest the ground level.

We had recorded defect indicators by 4-foot sections up the stem. Therefore, we calculated X_5 and X_6 for all combinations of 4-foot sections within the first 16 feet of each tree. Each of the different defect counts and measures were divided by the length of the section used to count or measure instead of total merchantable stem length.

The R^2 values and residuals for the original regression analyses, where X_5 and X_6 were calculated using all defects per tree and total merchantable stem, were compared with those obtained when each of the new values of X_5 and X_6 were used. The different 4-foot section combinations worked about equally well (R^2 values ranged from 0.80 to 0.91), with R^2 values almost equal to those obtained using total defects and stem length (values ranged from 0.81 to 0.93). One possible explanation for this came from our defect analysis study. We found, on the average, that 89 percent of all defect types were fairly uniformly distributed by 4-foot sections up the stem (Stayton *et al.* 1970). Therefore, because the defects counted or measured for variables X_5 and X_6 are divided by the stem length used, these variables would remain almost constant regardless of the 4-foot section combination used.

Values of X_5 and X_6, calculated for all 90 trees using the optimum grading sections 0 to 4 feet and 0 to 8 feet, were combined with other independent variables to develop prediction equations for estimating lumber grade yields. These two sets of equations were tested on 66 additional trees to select the final grading section. The 0 to 8 foot section was selected on the basis of best performance.

Independent Variables

The independent variables used to develop equations for estimating lumber grade yields in standing sugar maple trees were:

X_1 = Diameter breast height, inches

X_2 = Merchantable stem length, feet

X_3 = Merchantable stem volume inside bark (Smalian formula), cubic feet[3]

X_4 = Stem taper, inches per foot[4]

X_5 = Number of knots, bumps, and surface rises + 0.62 (number of bark distortions + number of adventitious buds and/or epicormics) within first 8 feet of stem divided by 8 feet, number per foot

X_6 = Total length of open seams + 0.67 (total length of overgrown seams) + 0.49 (total length of flutes) within first 8 feet of stem divided by 8 feet, inches per foot

X_7 = Average tree diameter, inches

X_8 = Diameter breast height squared.

Average tree diameter (X_7) was calculated using the equation,

$$D = \left(\frac{4\ X_3}{\pi\ X_2}\right)^{1/2}$$

Because X_3 was obtained for each tree by summing log volumes, D is a good representative average diameter.

Although there is a total of eight independent variables, only a minimum number of tree measurements were required. All of the variables were generated from these measurements: (1) counts and measures of certain defect indicators within the first 8 feet of the stem, (2) d.b.h., (3) several d.o.b. measurements up the stem, and (4) stem length.

Equations

Prediction equations were calculated for each lumber grade – FAS (Y_1); SEL (Y_2); #1C (Y_3); #2C (Y_4); #3A (Y_5); and #3B (Y_6):

$$Y_1 = 48.778 - 4.430\ X_1 - 0.440 X_2 + 1.115\ X_3 - 63.646\ X_4 - 7.376\ X_5 + 0.063\ X_6 - 0.122\ X_7 + 0.115\ X_8$$

$$Y_2 = 6.743 - 0.777\ X_1 - 0.024\ X_2 + 0.523\ X_3 - 33.844\ X_4 - 2.743\ X_5 + 0.049\ X_6 + 0.125\ X_7 + 0.016\ X_8$$

$$Y_3 = 29.242 - 1.586\ X_1 - 0.325\ X_2 + 1.826\ X_3 - 119.850\ X_4 - 1.683\ X_5 + 0.076\ X_6 + 0.176\ X_7 + 0.020\ X_8$$

$$Y_4 = -\ 12.301 + 3.308\ X_1 - 0.190\ X_2 + 1.105\ X_3 - 34.130\ X_4 + 3.930\ X_5 + 0.125\ X_6 - 0.378\ X_7 - 0.095\ X_8$$

$$Y_5 = -\ 32.159 + 4.227\ X_1 + 0.107\ X_2 + 0.236\ X_3 - 2.366\ X_4 + 1.726\ X_5 + 0.034\ X_6 - 0.232\ X_7 - 0.113\ X_8$$

$$Y_6 = -\ 69.126 + 10.101\ X_1 + 0.579\ X_2 + 0.907\ X_3 - 41.147\ X_4 + 6.114\ X_5 + 0.009\ X_6 - 0.421\ X_7 - 0.288\ X_8$$

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[3] *Bark volume can be accurately estimated (Stayton and Hoffman 1970) and used to calculate merchantable stem volume inside bark.*

[4] *Stem taper was calculated using bottom and top d.o.b. measurements of merchantable stem.*

The R^2 values for these equations are as follows:

Lumber Grade	R^2
FAS	0.71
SEL	.73
#1C	.89
#2C	.94
#3A	.81
#3B	.84

One reason high R^2 values were obtained is because we used lumber grade yields obtained from published tables as dependent variables. Because these tables give average yields by log size and grade, the variation about the means is eliminated from our regression analysis.

Testing the Equations

The regression analyses indicated that our proposed methodology could be used to develop equations for estimating lumber grade yields for standing hardwood trees. However, the real test of any grading system is whether it accurately predicts yields for trees other than those used to develop the equations. To test our equations, we used data collected for 199 sugar maple trees from four different National Forests – 66 trees from the Ottawa National Forest, 39 from the Monongahela National Forest, 45 from the Green Mountain National Forest, and 49 from the White Mountain National Forest.[5] Because our original 90 sample trees came from the Ottawa National Forest, we were able to test the equations on trees from the same general area and also on trees from the Northeast and West Virginia.

Ottawa National Forest Test

The prediction equations (page 3) gave good estimates of total lumber yield and dollar value for the 66 trees from the Ottawa National Forest. Total lumber yield and dollar value were underpredicted by 7 and 4.4 percent, respectively. The difference between observed and predicted values within lumber grades ranged from 3 to 61 percent. The largest differences occurred for the #3A and 3B grades. The percent differences for the other grades ranged from 3 to 24 percent. The observed and predicted combined yields of #1 Common and Better lumber were almost identical – 14,036 bd. ft. versus 14,078 bd. ft. respectively (table 1).

[5] *The lumber grade yields and tree-stem measurements for these trees were provided by the USDA Forest Service, Northeastern Forest Experiment Station's Grade and Quality of Hardwood Timber Project, Columbus, Ohio.*

Table 1.—*Comparison between observed and predicted lumber yields and dollar values for 66 sugar maple trees from the Ottawa National Forest*

Grade		Observed		Predicted		Bd.-ft. difference	Dollar-value difference
		Yield	Value 1/	Yield	Value		
		(Bd.ft.)	(Dollars)	(Bd.ft.)	(Dollars)	(Percent)	(Percent)
FAS		2,705	708.71	3,295	863.29	-22.0	--
SEL		3,217	778.51	2,439	590.24	24.0	--
#1C		8,114	1,338.81	8,344	1,376.76	- 3.0	--
	Subtotal	14,036	2,826.03	14,078	2,830.29	- 0.3	- 0.2
#2C		6,322	568.98	5,002	450.18	21.0	--
#3A		3,757	262.99	1,450	101.50	61.0	--
#3B		4,347	282.56	5,926	385.19	-36.0	--
	Subtotal	14,426	1,114.53	12,378	936.87	14.0	16.0
	Grand total	28,462	3,940.56	26,456	3,767.16	7.0	4.4

1/ Dollar values for tables 1 through 4 were taken from "Hardwood Market Report Weekly News Letter," Jan. 31, 1970, Memphis, Tennessee.

Other National Forest Tests

Total lumber yield and dollar value were underpredicted by 4 and 14 percent, respectively, for the 39 trees from the Monongahela National Forest. Observed and predicted lumber yields within grades, however, differed by 13 to 140 percent. The predicted yield of #1 Common and Better lumber was 14 percent lower than the observed — 4,478 bd. ft. versus 5,231 bd ft. (table 2).

Total lumber yields and dollar values were overestimated for the trees from the White and Green Mountain National Forests by about 24 and 30 percent. Within-grade yield predictions were considerably different from observed values — ranging from 7 to 64 percent (tables 3 and 4).

Table 2.—*Comparison between observed and predicted lumber yields and dollar values for 39 sugar maple trees from the Monongahela National Forest*

Grade		Observed		Predicted		Bd.-ft. difference	Dollar-value difference
		Yield	Value	Yield	Value		
		(Bd.ft.)	(Dollars)	(Bd.ft.)	(Dollars)	(Percent)	(Percent)
FAS		1,143	299.47	706	184.97	38.0	--
SEL		1,491	360.82	831	201.10	44.0	--
#1C		2,597	428.51	2,941	485.27	- 13.0	--
	Subtotal	5,231	1,088.80	4,478	871.34	14.0	20.0
#2C		2,392	215.28	2,147	193.23	10.0	--
#3A		1,794	125.58	763	53.41	57.0	--
#3B		1,169	75.99	2,815	182.98	-140.0	--
	Subtotal	5,355	416.85	5,725	429.62	- 7.0	- 3.0
	Grand total	10,586	1,505.65	10,203	1,300.96	4.0	14.0

Table 3.—*Comparison between observed and predicted lumber yields and dollar values for 45 sugar maple trees from the Green Mountain National Forest*

Grade		Observed		Predicted		Bd.-ft. difference	Dollar-value difference
		Yield	Value	Yield	Value		
		(Bd.ft.)	(Dollars)	(Bd.ft.)	(Dollars)	(Percent)	(Percent)
FAS		679	177.90	476	124.71	30.0	--
SEL		1,977	478.43	703	170.13	64.0	--
#1C		2,732	450.78	2,547	420.26	7.0	--
	Subtotal	5,388	1,107.11	3,726	715.10	31.0	35.0
#2C		2,816	253.44	1,867	168.03	34.0	--
#3A		1,335	93.45	693	48.51	48.0	--
#3B		2,054	133.51	2,617	170.11	-27.0	--
	Subtotal	6,205	480.40	5,177	386.65	17.0	20.0
	Grand total	11,593	1,587.51	8,903	1,101.75	23.0	31.0

Table 4.—*Comparison between observed and predicted lumber yields and dollar values for 49 sugar maple trees from the White Mountain National Forest*

Grade		Observed		Predicted		Bd.-ft. difference	Dollar-value difference
		Yield	Value	Yield	Value		
		(Bd.ft.)	(Dollars)	(Bd.ft.)	(Dollars)	(Percent)	(Percent)
FAS		304	79.65	254	66.55	16.0	--
SEL		1,188	287.50	627	151.73	47.0	--
#1C		3,272	539.88	2,296	378.84	30.0	--
	Subtotal	4,764	907.03	3,177	597.12	33.0	34.0
#2C		2,613	235.17	1,859	167.31	29.0	--
#3A		1,483	103.81	711	49.77	52.0	--
#3B		2,202	143.13	2,565	166.73	-16.0	--
	Subtotal	6,298	482.11	5,135	383.81	18.0	20.0
	Grand total	11,062	1,389.14	8,312	980.93	25.0	29.0

DISCUSSION

The predictions of total lumber yield and dollar value and lumber yields by grade for the 66 trees from the Ottawa National Forest indicate the grading system has potential use. The tree-stem characteristic that apparently caused the prediction inaccuracies for the Monongahela National Forest and particularly the White and Green Mountain National Forests was stem length. The average merchantable stem length for the 90 sample trees was 42 feet. The 66 trees from the Ottawa had an average length of 41 feet, but the Monongahela trees were 36 feet, and the White and Green Mountain trees only about 30 feet. Average d.b.h. for the Ottawa and Monongahela trees was about 3 inches larger than for the sample trees, but the White and Green Mountain trees had average d.b.h. values almost identical to the sample trees. Using prediction equations calculated by d.b.h. classes for the 90 sample trees (11.0 to 17.9 inches, 18.0 to 26.0 inches, and 11.0 to 26.0 inches) did not improve the accuracy of predicting lumber yields for trees from the four National Forests. Thus, best results will probably be obtained using different coefficients and perhaps different models for different areas. It may also be necessary to include new independent variables that adjust predicted yields for heavy insect damage or other defect factors peculiar to certain areas. Whether coefficients could be applied to large areas such as the Lake States or Northeast will have to be determined. If merchantable stem length is a critical variable, perhaps equations that apply to all areas or large areas such as the Lake States could be calculated by height classes. However, adequate sampling to obtain merchantable stem-length variation for important hardwoods would be necessary.

USE OF RESULTS

The real value of this research is the methodology for estimating lumber grade yields for hardwood timber. However, the prediction equations presented for sugar maple could have some immediate use. Hardwood species similar to sugar maple can possibly be evaluated using the same tree-stem characteristics. Of course, coefficients would have to be calculated for each species. Coefficients for all species should be calculated by area, using actual lumber grade yields from a larger sample size than 90 trees. Our equations are based on estimated yields obtained from published tables, which give average yields and have not been precisely tested for accuracy. In fact, one of the major difficulties in developing new systems for grading trees is that the accuracy of present systems is unknown. Therefore, there are no published results for comparison.

Equations developed using actual yields from a larger sample size could reduce the large differences between observed and predicted lumber grade yields we experienced for the 66 trees from the Ottawa. However, these differences may also have been reduced if we could have tested our equations on more than 66 trees. But even if the differences cannot be significantly reduced, definite over-or-underpredicting trends can possibly be established. Correction factors could then be applied to give accurate estimates of lumber grade yields. With such accurate estimates, dimension yields can then be calculated for standing timber using published dimension yield tables (Dunmire and Englerth 1967, Englerth and Schumann 1969, Schumann and Englerth 1967).

One such table published by Englerth and Schumann (1969) gives dimension yields for #1 Common and Better lumber where the total yield is 25 percent FAS, 25 percent Selects, and 50 percent #1 Common. Therefore, accurate predictions of #1 Common and Better lumber for standing trees can permit good dimension yield estimates. Our equations for sugar maple trees predicted #1 Common and Better lumber for the 66 trees from the Ottawa National Forest almost perfectly (table 1), and underpredicted this grouped lumber yield by only 14 percent for the 39 trees from the Monongahela National Forest (table 2). Thus, the proposed methodology offers great opportunity to develop prediction equations that accurately estimate total lumber yield and dollar value, individual or grouped lumber grade yields, and dimension yields for standing hardwood trees.

In addition, the system is simple to apply. Only a minimum number of tree measurements are required. The most difficult measurements, stem length and several d.o.b. measurements up the stem to determine stem taper and volume, can now be obtained using an optical dendrometer. In addition, a computer program is available for calculating stem volume directly from the dendrometer readings (Grosenbaugh 1963). Bark volume can be estimated (Stayton and Hoffman 1970) to obtain merchantable stem volume exluding bark. The grader will not have to determine which defect indicators are grade defects, only recognize and measure or count them; and photographic defect guides (Lockard *et al.* 1963, Marden and Stayton 1970) are available to help the grader recognize defect types. However, more precise information on the significance of defect types will have to be determined for important hardwood species in addition to sugar maple. The grader will not have to separate trees by grade classes because the proposed system is continuous. And, since the predicted values are in product yields rather than dollars, a change in product value will not require new equations.

This proposed grading system offers another possible significant breakthrough – development of a multiproduct predicting system for standing trees. Much of the credit for this possibility must go to those people who have shown that dimension yields can be accurately predicted from lumber grade yields. Combining the two systems permits estimation of lumber grade yields or dimension yields from standing trees. If additional relationships between lumber grade yields, dimension yields, and other products such as veneer can be established, these products can also be estimated from standing timber. A computer program could then be written that would combine these relationships to predict various product yields, and compare values to provide economic alternative decisions for timber and production managers. However, these alternate decisions would be based on trees yielding only one product. Segregation of tree-stem portions into best end-use classes is extremely difficult and would require additional information.

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- Participating with all State forestry agencies in cooperative programs to protect, improve, and wisely use our Country's 395 million acres of State, local, and private forest lands.
- Managing and protecting the 187-million acre National Forest System.

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