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BIOMASS YIELDS
from Allegheny Hardwood Thinning

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Abstract

To determine the yield of whole-tree biomass available from thinning Allegheny hardwoods, 64 sample plots were thinned in poletimber—small sawtimber stands located near Elkins, West Virginia. Biomass yields were derived from cut stand data and whole-tree weight equations, and averaged approximately 60 green tons per acre. Regression equations are given for predicting per-acre green-weight and dry-weight biomass yields from the square feet of basal area and the number of trees removed per acre of thinning.

MILLIONS OF ACRES of eastern hardwood poletimber—small sawtimber stands represent a major forest resource. The thinnings and improvement cuttings that are needed to increase the production of quality sawtimber from the stands can supply immense volumes of fiber, fuel, and sawn products. However, the resource has been underutilized because of inadequate markets for small logs and a lack of efficient systems for harvesting and processing small trees from thinnings. Productivity of the stands is below potential, and large volumes of potential wood products are lost to mortality.

A study of the product yields available from hardwood thinning was conducted by the Northeastern Forest Experiment Station's Forestry Sciences Laboratory at Princeton, West Virginia. Initial results from the study showed that roundwood yields from thinnings were 1,260 ft^3 per acre from Allegheny hardwoods, and 1,453 ft^3 from oak-hickory stands. Product yields included 17 percent factory grade sawlogs, 40 percent sawbolts, and 43 percent pulpwood and firewood (Craft and Baumgras 1978 and 1979).

Wood fiber from whole-tree chips is an alternative product available from hardwood thinnings. The need for more complete tree utilization has led to the development of whole-tree chippers that are becoming commonplace throughout much of the eastern United States. Brenneman and others (1978) reported that whole-tree utilization can increase yields from Appalachian hardwood stands by more than 30 percent over those of conventional roundwood harvesting. Martin (1977) reported a 35 percent increase when whole-tree chip yields were compared to roundwood yields from a cove hardwood stand. Application of this technology would result in significantly greater yields than the roundwood yields we have reported. The recent development of whole-tree weight equations has made it possible to estimate biomass yields available from thinnings, and to develop the biomass predictors presented in this report.

STUDY AND METHODS

Nine Allegheny hardwood stands along a 30-mile section of Middle Mountain near Elkins, West Virginia, were sampled. The elevation of these stands ranged from 3,000 to 3,800 feet. The combined species composition of all stands sampled by percent basal area was: black cherry (*Prunus serotina* Ehrh.), 42 percent; maple (*Acer saccharum* and *Acer saccharinum*), 31 percent; birch (*Betula alleghaniensis* and *Betula lenta*), 8 percent; beech (*Fagus grandifolia*), 7 percent; cucumbertree (*Magnolia acuminata*), 5 percent; white ash (*Fraxinus americana*), 3 percent; and other species, 4 percent.

Sampled stands represented overstocked poletimber—small sawtimber stands that occupied medium to good quality sites, and stands that should be thinned to increase production of quality sawtimber. Within these limits, we sampled a variety of stocking conditions and site qualities.

Sixty-four 1/10-acre plots were thinned. Initial stocking and species composition on each plot were determined by recording dbh and species for each tree that was 1.0 inch dbh or larger. The Allegheny hardwoods stocking guide published by Roach (1977) was used to determine the appropriate residual stocking for each plot. Because only overstocked stands were sampled, initial stocking exceeded 100 percent. Thinning reduced stocking to between 60 and 65 percent of full stocking.

Initial basal area of the sampled stands ranged from 132 ft^2 per acre to 184 ft^2 per acre. Residual basal area ranged from 77 ft^2 per acre to 113 ft^2 (Table 1). To create the canopy openings needed to stimulate crown growth on crop trees, the thinning removed a few dominant and codominant trees. However, to increase the mean stand diameter, thinning concentrated on trees in the lower diameter classes, and thinning increased the mean stand diameter an average of 2.3 inches.

Green-weight and dry-weight plot yields were estimated by summing the predicted whole-tree weights of all cut trees 1.0 inch dbh and larger. Tree weight predictions were made using mixed hardwood equations from three separate sources (Brenneman 1978, Monteith 1979, and Wartluft 1977). Different tree weight equations were used to determine how much thinning yield estimates would vary because of differences in the tree weight equations. Brenneman's and Wartluft's equations were developed from trees sampled in West Virginia; Monteith sampled trees in New York. All equations were based on samples that included those species removed from the thinning plots. However, Brenneman's sample included a species mixture most like that found on the thinning plots.

Each of the tree weight equations listed below uses dbh to predict whole-tree weight. The predicted weight, W, is expressed in pounds. Dbh, the independent variable, is measured in inches.

Tree weight equations:

Green

Brenneman $W = 4.3426 \text{ dbh}^{2.4594}$

Monteith $W = 20.2255 - 30.9727 \text{ dbh} + 15.5746 \text{ dbh}^2$

Wartluft $W = 4.7084 \text{ dbh}^{2.3938}$

Dry

Brenneman $W = 2.4544 \text{ dbh}^{2.4627}$

Monteith $W = 12.1798 - 18.7732 \text{ dbh} + 9.3177 \text{ dbh}^2$

Wartluft $W = 2.6011 \text{ dbh}^{2.4264}$

Plot yields and stocking parameters were converted to per-acre values. Various regression analyses were then performed to examine the relationship between per-acre biomass yields and certain stand parameters. Plot yield estimates, based on Brenneman's tree weight equations, were used in the regression analyses because of the similar species distribution and location of Brenneman's sample to the thinning plots. For the regression analyses each sample plot represented one observation.

Table 1.—Stocking of sample stands, trees ⩾ 1.0 inch dbh

Stand	Number of sample plots	Basal area per acre			Trees per acre			Mean dbh		
		Initial stand	Cut stand	Residual stand	Initial stand	Cut stand	Residual stand	Initial stand	Cut stand	Residual stand
		Square feet			*Number*			*Inches*		
1	9	148	71	77	517	384	133	7.2	5.8	10.3
2	8	151	75	76	481	370	111	7.6	6.1	11.3
3	8	180	70	110	535	321	214	7.9	6.3	9.7
4	6	140	49	91	790	508	282	5.7	4.2	7.7
5	6	147	59	88	837	582	255	5.7	4.3	7.9
6	6	152	53	99	813	548	265	5.8	4.2	8.3
7	7	132	55	77	741	471	270	5.7	4.6	7.2
8	6	155	54	101	463	278	185	7.8	6.0	10.0
9	8	184	71	113	684	434	250	7.0	5.5	9.1

The objective was to see if reliable biomass yield predictors, based on common available parameters—basal area and trees per acre, could be developed to provide a reliable alternative to the process of summing individual tree weight estimates.

RESULTS

Biomass yields

For each tree weight equation, the average estimated whole-tree biomass yield from all plots was:

Tree weight equation	*Green tons/acre*	*Dry tons/acre*
Brenneman	63.0	35.9
Monteith	65.4	39.0
Wartluft	59.8	35.3

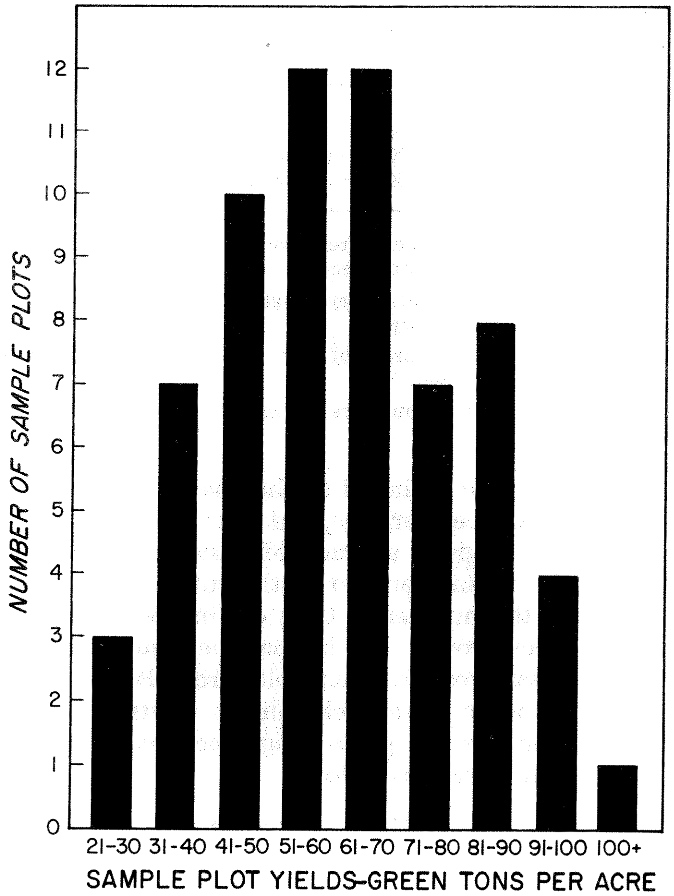
Monteith's tree weight equations provided the highest plot yield estimates, and Wartluft's the lowest (about 9 percent lower than Monteith's). For trees 3 to 10 inches dbh, Monteith's equation results in estimates that are higher than the other two equations (Table 2). Since most cut trees on the thinning plots were less than 10 inches dbh, Monteith's equation gave the highest plot yield estimates.

Table 2.—Predicted whole-tree green weight, in pounds, from tree weight regression equations

Tree dbh (inches)	Source of tree weight equation		
	Brenneman	Monteith	Wartluft
1	4	5	5
2	24	21	25
3	65	67	65
4	131	145	130
5	227	255	222
6	356	395	343
7	520	566	496
8	722	769	683
9	965	1,003	906
10	1,251	1,268	1,166
11	1,581	1,564	1,465
12	1,958	1,891	1,804

The variability of sample plot yields is shown in Figure 1. Estimates of weight yield for the thinned plots based on Brenneman's tree equation ranged from 26 green tons per acre to more than 100 green tons per acre. Yields estimated from Monteith's and Wartluft's equations showed almost an identical range.

Figure 1.—Frequency distribution of sample plot weight yields (estimated from Brenneman's tree weight equation).



The results from the regression analyses show that most of the variation between estimated plot yields can be explained by the amount of basal area removed in thinning

(Table 3). By adding the number of cut trees per acre to the thinning yield model as a second independent variable, the standard error of the estimate is reduced by more than 30 percent (Table 3). This reduction in the error is linked to the relationship of basal area, trees per acre, and mean stand diameter. For a given amount of basal area removed, the mean diameter of the cut trees decreases as the number of trees cut increases. Smaller trees provide less biomass per square foot of basal area. For example, from Brenneman's equation the relationship between tree diameter and green weight per square foot of basal area is as follows:

Table 3.—Coefficients and statistics for thinning biomass yield prediction equations developed from Brenneman's tree weight equations

Regression equations and coefficients	Statistics	
	R^2	Standard error of estimate
$GW = 0.99793(X_1)$	0.945	5.37
$DW = 0.56784(X_1)$	.944	3.08
$GW = 1.15127(X_1) - 0.02345(X_2)$	.976	3.58
$DW = 0.65570(X_1) - 0.01344(X_2)$	.976	2.05

GW = tons/acre, green weight from trees 1.0 inch dbh and larger.

DW = tons/acre, dry weight from trees 1.0 inch dbh and larger.

X_1 = basal area cut/acre, trees 1.0 inch dbh and larger.

X_2 = trees cut/acre 1.0 inch dbh and larger.

Dbh	*Pounds/ft²*
2	1,091
3	1,327
4	1,506
5	1,669
6	1,816
7	1,948
8	2,069
9	2,183
10	2,294

Therefore, the trees-per-acre coefficient has a negative sign that decreases the weight estimate as the number of trees cut per acre increases. For example, if 60 ft² of basal area and 300 trees are cut per acre, the estimated yield is 62 green tons per acre. If the basal area cut remains at 60 ft², and the number of trees cut per acre is increased to 600, the estimated yield is reduced to 55 green tons per acre (Table 4).

If only basal area removed is used to predict weight yields, the results will be most reliable when the mean diameter of the cut stand is close to the average, which was 5.2 inches dbh, for all stands sampled. However, for preliminary surveys, basal area removed provides an adequate estimate of thinning biomass yields. To make these estimates, the stand yield equations in Table 3 can be applied directly to stand data, or these equations can be used to develop a yield table similar to that in Table 5. For a quick estimate, a rule-of-thumb that can be used is 1 green ton for each square foot per acre of basal area removed.

A more accurate weight yield estimate can be obtained from the stand yield models by using both basal area and trees per acre. This reduces the error due to variations in cut stand diameter (Table 3). These equations can also be used to develop biomass yield tables (Table 4).

To use the weight yield equations or tables, make a reliable estimate of either basal area, or basal area and the number of trees to be cut per acre of thinning. Although the biomass yield equations were developed from fixed area plot yields, they can be applied to cut stand parameters obtained from either variable radius prism plots or fixed area plots. Sample plot data can be summarized for a particular stand, and then the average stand parameters can be used with the yield equations or tables to predict thinning weight yields. However, these results should be applied only to stands with mean cut tree diameters within the range of the plots sampled in this study—3.0 to 9.0 inches dbh. These yield models might not provide realistic results when used outside this diameter range.

Table 4.—**Biomass yield table using basal area and trees cut per acre to predict thinning yields from trees $\geq$ 1.0 inch dbh (based on yield model developed from Brenneman's tree weight equation).**

Number of trees cut per acre	Basal area removed in thinning, square feet per acre						
	30	40	50	60	70	80	90
				Green tons/acre			
100	32	44	55	67	78	90	101
200	30	41	53	64	76	87	99
300	28	39	51	62	74	85	97
400	25	37	48	60	71	83	94
500	23	34	46	57	69	80	92
600	20	32	43	55	67	78	90
700	18	30	41	53	64	76	87
800	16	27	39	50	62	73	85
				Dry tons/acre			
100	18	25	31	38	45	51	58
200	17	24	30	37	43	50	56
300	16	22	29	35	42	48	55
400	14	21	27	34	41	47	54
500	13	20	26	33	39	46	52
600	12	18	25	31	38	44	51
700	10	17	23	30	36	43	50
800	9	15	22	29	35	42	48

Table values within box rules correspond to the range of sample data used to develop the table.

Table 5.—Biomass yield tables for using basal area to predict thinning biomass yield, tons per acre

Basal area removed (ft^2/acre)	Predicted biomass yield	
	Green weight	Dry weight
20	20	11
30	30	17
40	40	23
50	50	28
60	60	34
70	70	40
80	80	45
90	90	51

Trees per ton of biomass

The mean diameter of the cut trees affects harvesting efficiency as well as biomass yields. As tree diameter decreases, the number of cut trees per ton of biomass increases. Thus, more trees must be cut, skidded, and chipped per ton of chip yield. Therefore, the mean diameter of the cut stand is an important consideration in harvesting, especially in thinning operations that generally concentrate on the smaller diameter trees.

Mean stand diameter (MSD) can be calculated from basal area (BA) and trees per acre (TA) using the following equation:

$$MSD = \sqrt{\frac{BA}{TA}(183.35)}$$

Regression equations for predicting the number of trees per green ton were developed from the estimated biomass yields and cut stand parameters on each plot. The equation, $Y = aX^b$, uses mean cut stand diameter as X. The coefficients and statistics are:

Source of tree-weight equation	Coefficients *a*	Coefficients *b*	Statistics R^2	Statistics Standard error
Brenneman	289.04	-2.258	0.991	0.393
Monteith	266.74	-2.239	.993	.203
Wartluft	287.66	-2.226	.997	.348

The number of cut trees per ton of biomass harvested, predicted by the regression developed from Brenneman's tree weight equation, is shown below. When mean stand diameter drops below 6 inches dbh, the number of trees per ton rapidly increases. For example, if the mean stand diameter is only 4 inches, more than 12 trees must be harvested per ton of biomass, versus only 2 trees at 9 inches.

Mean stand diameter (inches)	*Number of cut trees per ton of biomass harvested*
3	24.2
4	12.6
5	7.6
6	5.1
7	3.6
8	2.6
9	2.0
10	1.6

DISCUSSION

Predicting thinning biomass yields by the basal area or basal area and number of trees removed provides a simple, yet reliable alternative to summing tree weights estimated from cut tree diameters. The error terms for these models include only the variance between the sum of the estimated tree weights and the predicted sum of the estimated tree weights. Because the stand yield models were developed from estimated tree weights, there is an added source of error in the estimates provided by these models—the error in the estimated tree weights. Because of the relatively low error in the tree weight models, this additional source of error should not significantly affect the reliability of the stand yield models. Furthermore, similar error would also be encountered when summing estimated individual tree weights.

The tree weight equations developed by Brenneman, Monteith, and Wartluft provided differing plot weight yield estimates. However, the differences in estimated plot yields attributable to the tree weight equations were relatively minor compared to the differences between plots related to variations in stocking. Individual plot yields differed by as much as 75 green tons per acre (Figure 1). However, the difference in individual plot yields between tree weight equations averaged less than 6 green tons per acre, and exceeded 9 tons on only four plots.

The thinning yield models were developed from mixed or combined hardwood tree weight equations. These models should provide reliable results when applied to stands with the mixture of species common to Allegheny hardwood or northern hardwood timber types.

In the fully stocked Allegheny hardwood stands that were sampled, thinnings yielded approximately 60 tons of whole-tree biomass per acre. Millions of acres of eastern hardwoods could be thinned, and the biomass available from thinning represents a tremendous supply of wood fiber or fuel.

New forest mensuration techniques and new methods of harvesting and processing small trees from thinnings will be required to utilize this resource. The thinning yield models that were developed can aid in the development of this technology. These models can be used with conventional cruising methods to predict thinning yield weights and values. Stand or tract weight yield predictions can also be used in the determination of harvesting cost estimates and in the selection of efficient harvesting systems.

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