AN INTEGRATED GROWTH AND YIELD SIMULATOR FOR PREDICTING LOBLOLLY PINE DRY WEIGHT PULP YIELDS[1]

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ABSTRACT

Growth and yield simulators are a valuable tool for forest managers in predicting future stumpage yields and selecting the economically best management strategies and rotation ages. These projections are appropriate for the sellers of stumpage but may not be appropriate for the producers of forest products who also own and manage the raw resource. To identify the most desirable management strategies for land-based mills, the yield model must be capable of making good estimates of final product yields, such as dry weight of pulp, lineal feet of veneer, and size and grade distribution of lumber. The Mississippi State University loblolly pine (*Pinus taeda* L.) growth and yield simulator has a dry weight pulp yield model fully integrated in the program. Dry weight pulp yields were estimated from stand and tree characteristics using a neural network model for predicting the distribution of wood chip weight by thickness class and a single tree dry weight pulp yield model. These models were embedded in the profile function based tree volume estimator of a cutover site-prepared plantation loblolly pine growth and yield simulator. The resulting model produced estimates of dry weight pulp yields comparable to actual yields. The Windows application growth and yield simulator generates harvested volumes by stumpage class, dry weight pulp yield, and net present values for user selected management regimes and merchandizing standards. It is available at http://www.cfr.msstate.edu/fwrc/software.htm (loblolly). Both stumpage sellers and pulp producers can use the software to place a value on chips from stands according to their expected stumpage and dry weight pulp yields or to select management strategies to maximize yields.

Keywords: Growth and yield simulator, neural network, single tree dry weight pulp yield, wood chip thickness.

INTRODUCTION

Efficient and cost-effective utilization of wood fiber requires forest managers to relate the manipulation of stand characteristics to the quality, quantity, and value of projected raw material and final products. Growth and yield simulators project green weights and wood volumes by product category, given stand characteristics and merchandizing specifications, but no published models have ever projected final product yields such as dry weight of pulp. Tong et al. (2005) examined the economic impact of pre-commercial thinning in jack pine (*Pinus banksiana* Lamb.) stands at various stand densities based on optimal lumber value recovery. This evaluation was based on a controlled study, however,

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and was not within the context of a growth and yield model. Prediction of dry weight pulp yields, or other final products, from stand and individual tree characteristics would allow mill managers with a land base to manipulate management and harvesting strategies to increase pulp yields per unit cost. The purchase price of chips could also be based on their projected yield at the mill.

Factors influencing dry weight pulp yields can be categorized as pulping process variables or component factors affecting wood chip quality and size (Kleppe 1970). Chip quality is best characterized by specific gravity (Kleppe 1970), which is affected by geographic variation (Zobel et al. 1972), competitive position (Tasissa and Burkhardt 1998), height in the tree bole, and age (Kleppe 1970; Zobel et al. 1972). Chip size or thickness is influenced by stand characteristics (Flowers et al. 1992; Koger et al. 1993; Schultz et al. 1999), chipper mechanics (Dubois et al. 1991; Twaddle and Watson 1990; Uelmen 1993), and chip screening at the mill (Christie 1987; Tikka et al. 1993) and is important because specific pulping processes require different chip thickness ranges. Chip thicknesses below or above optimal ranges can produce overcooked (weak or low yield) or undercooked (requiring repulping) pulp (Christie, 1987; Worster et al. 1977). By controlling chip thickness, the mill manager can increase yield per unit cost.

The objective of this study was the extension and integration of models described in previous work (Matney and Farrar 1992; Schultz and Matney 2002; Schultz et al. 1999) to relate forest stand growth and yield to dry weight pulp yields under realistic management options. Predicting dry weight pulp yields from stand and tree characteristics involves a complex integration of models that estimate: 1) the distribution of chip weight by chip thickness size class, 2) specific gravity and moisture content at any given height in the tree bole, and 3) growth and yield under various stand conditions, merchandizing scenarios, and pulping kappa numbers. The individual models described below were integrated by embedding the first two models into the profile function based tree volume estimator of a cutover site-prepared plantation loblolly pine (*Pinus taeda* L.) growth and yield simulator.

MODELS AND METHODS

Distribution of wood chip weight by thickness size class

Wood chip thickness is a major factor in the performance of pulp digesters and subsequent yield and pulp quality (Becker 1992; Borlew and Miller 1970; Tikka et al. 1993) and is an important component in estimating dry weight pulp yields. Stand age, dbh, and chip position in the tree influence the distribution of chip weights by thickness size class (Koger 1994). We used chip thickness measurements taken on 11,771 individual loblolly pine chips from stands of four ages, five dbh classes, and three stem positions to develop an artificial neural network model to predict distributions of chip weights by thickness class (Schultz et al. 1999). NeuralWare's NeuralWorks Professional II/Plus (NeuralWare, Inc., Pittsburgh, PA, USA) software was used to construct a fully connected, hetero-associative, feed forward, back-propagation network with two hidden layers. There were four input nodes to the neural network (stand age, dbh class, stem position, and chip thickness), twelve hidden layer nodes, and one output node (cumulative proportion of total weight by chip thickness). The optimal network architecture and parameters were selected on the basis of lowest root mean square error. The parameters of the resulting nonlinear model are adjusted during a training (learning) phase by back-propagating errors in an iterative gradient descent method, as opposed to a least squares procedure. Even though the root mean square error was used as a convergence criterion, there is no guarantee that the neural network model will obtain the minimal root mean square error.

NeuralWorks writes the neural network model, in a C programming language module, which can then be called from other programs to project distributions or estimate fit statistics. The neural network model was compared to two good previously developed parametric models based on the Weibull distribution function (Schultz et al. 1999). The neural network produced a higher index of fix (0.957) and lower overall bias (0.0) than the two parametric models and was adapted for predicting chip weight distributions.

Sensitivity analyses showed that thicker chips are produced by younger stands at the lower positions within the bole. Smaller dbh classes produced more narrow and less right skewed (larger chips) chip thickness distributions than larger dbh classes. Differences of only one millimeter in chip thickness present opportunities to manage stands for the manipulation of pulp quality and pulping efficiencies. Stand age and dbh class are readily manipulated by silvicultural treatments, and stem position might be manipulated during harvesting or chipping operations to optimize chip mixes. The neural network model estimates the proportion of chip weights falling into thickness classes for combinations of stand age, dbh class, and stem position. When embedded in a growth and yield model, weights for each thickness class can be determined over a range of site indices, spacings, and merchandizing specifications.

Single tree dry weight pulp yield model

Five models were combined to estimate the actual dry weight pulp yield of a single tree by chip size class. These equations estimated the

1) dry weight basis moisture content of bole wood by stem position,
2) specific gravity of wood from moisture content,
3) inside bark tree profile,
4) dry weight of pulp yield from kappa number, and
5) the proportion of weight by chip thickness size class.

These models give the growth and yield simulator the ability to predict tree pulp yield by chip size class at any stand age for a wide variety of stand management strategies.

The dry weight basis moisture content model was constructed from data reported by Dubois (1994), and data scaled from Fig. 1 in Clark and Daniels (2000). The Dubois (1994) data were used to construct equations to predict average wet basis percent moisture content ($\overline{M}$) from age (A) and dbh (D) in cm (Eq. 1). A proprietary data set of 750 specific gravity disk observations from 60 trees sampled in a cutover site-prepared planted loblolly pine tree volume study were used to find equations to predict 1) average specific gravity (S) from dry weight basis percent moisture content for loblolly pine tree stem bole wood (Eq. 2), and 2) the change in wet basis percent moisture content of bole wood per meter of bole length (L) from age (Eq. 3).

$$\ln \overline{M} = 3.87934 + 3.9468 \left(\frac{1}{A}\right) - 3.0460 \left(\frac{1}{D}\right) \tag{1}$$

$R^2 = 75.1\%$, $S_{y.x} = 0.044$

$$\ln S = -0.20758 - 0.0043993\, \overline{M} \tag{2}$$

$R^2 = 73.8\%$, $S_{y.x} = 0.06095$

$$\frac{dM}{dL} = 0.363 - 0.000769\, A \tag{3}$$

$R^2 = 42.1\%$, $S_{y.x} = 0.062$

Used in conjunction, Eqs. (1–3) allow for the construction of Eq. (4) that estimates the percent moisture content of bole wood at any height above the ground, M(h, μ), from age, dbh, and total height. The equation is simple because the rate of change in bole moisture content is not a function of the height above ground but, for all practical purposes, is a constant for a tree of given age.

$$M(h, \mu) = \overline{M} + \frac{dM}{dL}(h - \mu) \tag{4}$$

where

h = height above ground in meters, and

μ = the centroid of the weight of bole wood; that is, the height above ground where the stem bole wood percent moisture is equal to the average moisture content of the entire wood in the bole, $\overline{M}$.

After the value of μ is determined, Eq. (4) can be applied to calculate the moisture content of bole wood at any height above the ground. Finding a value for μ (the center of mass or centroid), requires solving the center of mass equation (Eq. 5) for μ.

$$\frac{\textit{Weight of bole water}}{\textit{Green weight of bolewood}}\,100=\overline{M}=\frac{\int_s^{h_t} M(h,\mu)W(h)dh}{\int_s^{h_t} W(h)dh} \tag{5}$$

$$=\frac{\int_s^{h_t} M(h,\mu)dW}{\int_s^{h_t} dW}$$

where

W (h) = the cross-sectional green weight of wood in kilograms per meter at height h,

s = stump height in meters,

h_t = total tree height in meters, and

dW = W(h) dh = the green weight (mass) differential in kilograms at the height h.

Writing an explicit equation for dW involves the use of a tree profile function (Eq. 6). A tree profile function is an equation that predicts the diameter of a tree bole at any height above the ground.

$$dW=D_g\left(\frac{\pi}{4}\right)[d(h)]^2\,dh \tag{6}$$

where

D_g = the green weight density of the bole in kilograms per cubic meter wood and is assumed to be a constant in this paper, and

d(h) = the profile function to predict inside bark diameter of the bole in meters at a height of h meters above the ground.

The term $(\pi/4)[d(h)]^2$ is the cross-sectional area of the stem in square meters which, when multiplied by the green wood density D_g and the height differential dh, becomes the bole wood green weight differential dW.

The explicit Eq. (7) solvable for μ is thus

$$\frac{D_g\left(\frac{\pi}{4}\right)\int_s^{h_t}\left[\overline{M}+\frac{dM}{dL}(h-\mu)\right][d(h)]^2\,dh}{D_g\left(\frac{\pi}{4}\right)\int_s^{h_t}[d(h)]^2\,dh}=$$

$$\frac{\int_s^{h_t}\left[\overline{M}+\frac{dM}{dL}(h-\mu)\right][d(h)]^2\,dh}{\int_s^{h_t}[d(h)]^2\,dh}=\overline{M}. \tag{7}$$

With some arduous algebraic manipulations of Eq. (7), that are too lengthy for inclusion here, the resulting solution for μ is the simple Eq. (8).

$$\mu=\frac{\int_s^{h_t} h[d(h)]^2\,dh}{\int_s^{h_t}[d(h)]^2\,dh} \tag{8}$$

Most tree profile equations predict relative dbh (d/dbh) as a function of the single independent variable relative height (h/h_t). In this case μ will be a constant proportion of total height. Relative height is the ratio of height above ground (h) to total height (h_t), and varies between 0 and 1. The value for μ for the profile function embedded in the growth and yield simulator is 0.313 h_t .

It should be noted that Eq. (8) is also height to the average cross-sectional area of the bole. This occurred because moisture content (Eq. 4) is a linear function of h and a constant density, D_g, was assumed. In the case that the density and moisture content functions were more complex, Eq. (7) would be solvable for μ only by a numerical solution algorithm for determining the roots of a nonlinear equation.

Dry weight pulp yields for individual trees (Eq. 10) are computed by converting the wet weight moisture content differential in Eq. (5) to a dry weight basis and calculating the differential of dry weight pulp yield from Kleppe's equation (Kleppe 1970) (Eq. 9) for a specific kappa number. Eq. (2) is used to supply the dry weight basis specific gravity required in Eq. (9).

$$TPY=16.5+49.8S+0.14Kappa \tag{9}$$

where

TPY = total pulp yield as a percentage of oven-dried weight.

$$dW' = W'(h)\left(\frac{TPY}{100}\right) dh \qquad (10)$$

where

W′(h) = the cross-sectional dry weight of wood in kilograms per meter at height h, and

dW′ = the dry weight pulp yield differential in kilograms at height h.

Numerical integration of the differentials over the height range from stump to a specified top diameter results in an estimated pulp yield for individual tree bole wood.

Growth and yield simulator

The distribution of wood chip weight by thickness size class and single tree dry weight pulp yield models were integrated with a cutover site-prepared loblolly pine growth and yield simulator (Matney and Farrar 1992) to provide realistic dry weight pulpwood yield estimates for thinned-stand management regimes. Data for development of the growth and yield simulator were collected from 258, 1/4-acre permanent plots in Arkansas, Louisiana, Mississippi, and Alabama. Plots covered a wide range of stand ages, densities, and site indices. Three types of thinnings (from below, row, and combination row and from below) were applied to a subset of plots ranging from 25% to 50% basal area reduction. Stands were not thinned below 65 ft^2 basal area per acre. Measurements occurred on a 3-year cycle from 1982 until 1994. Measured variables included dbh, total tree height, height to base of live crown, tree damage and disease, quality class, and tree location coordinates.

Prethinning diameter distributions were approximated by recovering the parameters of a three-parameter Weibull distribution. This distribution produces a tree list of diameters and the number of trees per acre represented by each diameter. Thinnings are applied to the tree list and weighted constrained least squares procedures are then employed to allocate mortality and diameter growth. Component survival and stand level prediction equations are given in Matney and Farrar (1992). Tree volumes are calculated using tree list diameter distributions, a total tree height prediction equation, and profile equations described in Ledbetter et al. (1986). The growth and yield simulator's user interface allows complete or partial specification of the initial stand and selection of merchandizing standards. Age, surviving trees per acre, and site index are the only required inputs. Merchantability specifications allow product threshold designations and dbh and merchantable top diameter limits.

Integration of models

The single tree dry weight pulp yield and chip thickness distribution models were embedded in the profile function based tree volume estimator of the growth and yield simulator to predict dry weight pulpwood yields over the height range of individual trees. The profile functions predict inside and outside bark diameters at any height above the ground. Dry weight pulp yield differentials (Eq. 10) for any height above ground were numerically integrated over the entire length of each tree bole using a 0.6096-m (2-ft) bolt length to obtain total pulp yield per tree. At each height interval in the bole, the dry weight pulp yield function is evaluated from its composite functions for diameter, specific gravity, moisture content, and weight distributions of chip thickness classes at selected kappa numbers. The neural network is called five times (once for each chip thickness class) at each height interval. Stand age, dbh class, chip height in the bole, (butt, middle, and top) and chip thickness class are passed as inputs to the neural network and proportion of total chip weight by thickness class is returned to the growth and yield simulator. The estimated chip weight proportions are then used to partition dry weight pulp yield into chip thickness classes. Dry weight pulp yields are accumulated by thickness class and kappa number as the integration proceeds along the entire length of each tree bole and for all trees in a given stand.

APPLICATION

For the purpose of illustrating the computations required to estimate pulp yield from a tree's characteristics, a single differential dry weight pulp yield is calculated at a height 10 m above ground for a tree 32 cm in dbh, 20 m in total height, 25 years old, and stump height of 0.15 m. When these differentials are calculated at fixed intervals (dh) up the bole, their sum (integration) is the total pulp yield in the tree. The kappa number assumed for the computations is 45. Kleppe's equation (Eq. 9) is used to calculate the total pulp yield as a percentage of oven-dried weight for each dry weight differential from kappa number and specific gravity. Equation (11) is the inside bark profile equation (Ledbetter et al. 1986) extracted from the growth and yield simulator. The function is constrained to pass through dbh (ib) at a breast height of 1.37 m and 0 when h equals h_t. Breast height is at 1.37 m instead of 1.3 m because the profile equation was constructed using the English measurement system.

$$d(h) = Dbh_{ib}$$
$$\left[b^{-1}h_t^{-c}\,ATan\left(-a^{-1}\ln\left[1-\left(1-\frac{h}{h_t}\right)^{(d-1)}\right]\right)\right] \quad (11)$$

where

d(h) = diameter inside bark in meters at a height of h meters above the ground,

h_t = total tree height in meters,

h/h_t = relative height,

ln = the natural logarithm,

ATan = the arc tangent expressed in radians,

Dbh_{ib} = 0.00749 + 0.912Dbh_{ob} = diameter inside bark in meters 1.37 meters above ground,

Dbh_{ob} = diameter outside bark in meters 1.37 meters above ground,

$$a = \frac{-\ln\left[1-\left(1-\frac{1.37}{h_t}\right)^{1/d}\right]}{Tan(bh_t^c)}$$

Tan = Tangent of the angle in radians, and

b = 0.89519, c = 22.23013, and d = 1.81439, are the estimated parameters of the model.

The profile function parameter a is used to force the function to pass through dbh at breast height.

From Eqs. (1), and (3)

$$\ln \overline{M} = 3.87934 + 3.9468\left(\frac{1}{25}\right) - 3.0460\left(\frac{1}{32}\right)$$
$$= 3.942,$$
$$\overline{M} = e^{3.942} = 51.52\%, \text{ and}$$
$$\frac{dM}{dL} = 0.363 - 0.000769(25) = 0.344\%.$$

From Eq. (8)

$$\mu = \frac{\int_{0.15}^{20.00} h[d(h)]^2\,dh}{\int_{0.15}^{20.00} [d(h)]^2\,dh} = \frac{4.9438}{0.7972} = 6.20\ meters.$$

From Eq. (4)

$$M(h, 6.20) = 51.52 + 0.344(h - 6.20).$$

Thus, at h = 10 m above the ground, the wet basis moisture content is

$$M = M(10, 6.20) = 51.52 + 0.344(10 - 6.20)$$
$$= 52.83\%,$$

which is equivalent on a dry weight moisture content, M_d, basis of

$$M_d = \frac{M}{100 - M}100 = \frac{52.83}{100 - 52.83}100 = 112.00\%$$

Since at the height of 10 m, the diameter inside bark in meters from Eq (11) is 0.200 m, the green weight differential is,

$$965\left(\frac{\pi}{4}\right)(0.200^2)dh.$$

Assuming a green weight density of 965 kg/m^3 for all heights above ground, the dry weight differential is thus,

$$965\left(\frac{\pi}{4}\right)(0.200^2)\left(1 - \frac{52.83}{100}\right)dh = 14.30dh.$$

Lastly, the differential of dry pulp weight from Kleppe's equation (Eq. 9) is calculated for a kappa number of 45

$$14.30\left(\frac{TPY}{100}\right)dh = 6.82dh$$

where

$$TPY = 16.5 + 49.8(0.50) + 0.14(45) = 47.7\%.$$

Equation (2) was used to calculate the specific gravity for the estimated dry weight basis, M_d of 112.00%,

$$\begin{aligned}\ln S &= -0.20758 - 0.0043993(112.00)\\ &= -0.700,\ \textit{and}\ S = e^{-0.700} = 0.50.\end{aligned}$$

The above differential calculations were performed for a height of 10 m above ground. Integration of all differentials over the height range of 0.15 to 20 m results in an estimated pulp yield of 263.1 kg for the bole wood of one tree.

RESULTS AND DISCUSSION

To demonstrate how knowledge of expected pulp manufacturing yields could affect management strategy choices, we investigated three loblolly pine multi-product regimes and one primarily sawtimber management regime similar to those currently being followed by forest products industries in the southeastern United States (Table 1). Harvested volumes and net present values (NPV) were used to evaluate potential investments and identify optimum management strategies. NPVs for stumpage (Table 1, column 12) contain revenues and costs for pulpwood, chip and saw, and sawtimber stumpage. NPVs for final product (Table 1, column 13) contain revenues and costs for chip and saw and sawtimber stumpage plus dry weight pulp production.

Assumptions for calculating volumes and NPVs included a cutover planting site, dominant site index of 22.2 m (73 ft) at base age 25, and initial planting densities of 1076 trees/ha (435 trees/ac) on a 1.5-m by 6.1-m spacing (5-ft by 20-ft) for sawtimber and 1683 trees/ha (681 trees/ac) on a 2.4 by 2.4-m spacing (8-ft by 8-ft) for the multiproduct regimes. The first multiproduct thinning removed 20% of rows followed by a selective thinning to 13.8 m^2/ha (60 ft^2/ac) basal area. The second multiproduct thinning was a selective thinning to 272 crop trees/ha (110 crop trees/ac). The sawtimber regime assumed an average stand dbh of 17.8 cm (7 in.) in 20 years; at which time, trees were selectively thinned to 272 crop trees/ha (110 trees/ac). Initial establishment costs of $494.21/ha included site preparation and planting (personal communication A. W. Ezell, Mississippi State University, June 15, 2005). Taxes and intermediate timber stand improvements were not included in NPV costs. Only primary costs were included so the reader could easily customize NPVs to specific management scenerios. Stumpage NPVs do not include logging costs because from the landowner's viewpoint they are not paying for harvesting costs. Logging costs for mill owners are accounted for within the assumption of a 6.5% net profit for the final product NPV, an estimate obtained from proprietary information. A June 2005 prime interest rate of 6% was used as the NPV rate of return.

Dry weight pulp yields (Table 1, columns 4–5) were calculated by the integrated growth and yield simulator for each management regime and kappa numbers 30 and 100, semi-bleached kraft and linerboard (unbleached kraft) grades, respectively. The final product NPV (Table 1, column13) used 6.5% of the Southern softwood semi-bleached kraft pulp price ($630/air-dried tonne averaged from June 2004 to May 2005) provided by Paperloop Inc. (personal communication Will Mies, May 20, 2005). Of the $630/air-dried tonne, 93.5% was assumed to be manufacturing costs and 6.5% profit. Pulpwood, chip and saw, and sawtimber prices were obtained from Forest2Market (http://msucares.com/forestry/prices/reports/2005/2.pdf) for the same June 2004 to May 2005 time period.

Predicted pulp yields were compared to proprietary yield data of unknown management regime and stand condition to validate the integrated model. Percent difference between the observed yields and the estimated yield, averaged over all removals for the four management

Table 1. *Expected loblolly pine pulpwood and sawtimber yields and net present values (NPV), based on stumpage and final product values, for three multi-product management regimes and one primarily sawtimber management regime.*

		Harvested volumes per hectare (ha)										
					Chip and saw			Sawtimber				
		Pulpwood	Pulp (tonnes)			- - - - - - - bd ft - - - - - - -			- - - - - - - bd ft - - - - - - -		NPV (2005 US $/ha)	
Management regime	Management[a] operation year	Green tonnes	Kappa[c] 30	Kappa[c] 100	Green tonnes	Doyle	Int.-1/4″	Green tonnes	Doyle	Int-1/4″	Stumpage[d]	Final product[e]
Multi-product regime 1	1st thin at 16	31.142	13.743	15.363	6.974	1006	971					
	2nd thin at 22	34.863	15.774	17.668	24.088	3452	3435					
	Harvest at 28	10.096	6.200	6.888	56.169	7252	8617	34.716	3452	6501	657	821
	Harvest at 30	9.028	6.303	7.002	54.115	7099	8276	45.741	4658	9870	672	839
	Harvest at 32	9.220	6.289	6.984	49.893	6454	7710	57.272	5876	10962	670	839
Multi-product regime 2	1st thin at 17	37.646	16.804	18.794	8.860	1268	1248					
	2nd thin at 23	31.212	14.079	15.774	25.581	3628	3689	1.328	131	240		
	Harvest at 29	11.314	6.957	7.743	54.464	6961	8429	36.793	3736	6877	667	848
	Harvest at 31	10.887	6.878	7.652	51.448	6570	7999	47.683	4828	11931	675	856
	Harvest at 33	11.025	6.914	7.688	47.337	6101	7364	58.993	6034	11347	672	854
Multi-product regime 3	1st thin at 18	45.599	18.788	21.022	13.718	1937	1960					
	2nd thin at 24	29.432	13.301	14.795	24.690	3430	3620	1.998	193	366		
	Harvest at 30	11.761	7.271	8.096	53.685	6946	8383	38.507	3885	7272	680	854
	Harvest at 32	12.061	7.286	8.110	49.265	6415	7618	50.060	5110	9541	687	861
	Harvest at 34	12.125	7.241	8.058	46.438	5921	7277	59.537	6192	11441	672	845
Sawtimber regime	20 yrs 7″ dbh[b]	35.364	15.866	17.743	34.909	4618	5204	6.374	613	1166		
	Harvest at 28	13.928	7.633	8.507	40.060	5118	6185	43.912	4428	8384	707	696
	Harvest at 30	12.134	7.380	8.222	39.593	5192	6061	53.852	5552	10374	714	718
	Harvest at 32	11.840	7.083	7.886	38.345	5043	5891	63.253	6578	12340	707	709

[a] Multi-product regimes include two thinnings and three possible harvest ages.

[b] Average stand dbh attained in 20 yrs at which time thinned to 272 trees/ha (110 trees/ac).

[c] Air-dried tonnes.

[d] Includes pulpwood, chip and saw, and sawtimber stumpage costs and revenues.

[e] Includes chip and saw and sawtimber stumpage and manufactured pulp (kappa number 30) costs and revenues.

regimes, was calculated by kappa number. For kappa number 30, estimated yields ranged from 0.9 to 1.46% (1.16 average) greater than the observed dry weight pulp yield. For kappa number 100, estimated yields ranged from 2.6 to 5.7% (4.2 average) less than the observed yield. Thus, the integrated pulp yield model produced reasonably close average estimates to the actual yields of unknown management and condition.

Harvesting 14 years after the first thinning and 8 years after the second thinning generated the highest NPVs across all selected multiproduct regimes in both product classes (stumpage and final product). If final harvest occurred two years earlier (12 years after first thinning and 6 years after second thinning), NPVs fell by $5 to $8/ha for stumpage and $7 to $18/ha for final product. If final harvest occurred two years later (16 years after first thinning and 8 years after second thinning), NPVs fell by $2 to $15/ha for stumpage and $0 to $16/ha for final product. Delaying first and second thinnings to 18 and 24 years after planting and harvesting at age 32 (regime 3) produced the highest multiproduct NPVs for the selected regimes.

Under the sawtimber management regime, harvesting 10 years after a thinning at 20 years of age produced the highest stumpage and final product NPVs. The sawtimber stumpage NPV was $27/ha higher than the best multiproduct regime, but the final product NPV was $143/ha lower than the best multiproduct regime. The large difference in final product NPVs reflects the greater and earlier production of dry weight pulp yields in the multiproduct regime and the absence of veneer (lineal feet) and lumber (grade and size distribution) production in the sawtimber regime.

On average, multiproduct final product NPVs were 26% greater than multiproduct stumpage NPVs. Over all multiproduct management regimes and harvest periods, there was a $30/ha difference within the range of stumpage NPVs and a $40/ha difference within the range of final product NPVs. When these dollar differences are multiplied over hundreds or thousands of hectares, the importance of predicting optimum management strategies for selling stumpage or producing final products is clearly apparent. Differences among final product NPVs would have been even greater if the assumption that profit was 6.5% of pulp revenue had been less conservative.

CONCLUSIONS

Growth and yield models have proven very valuable to forest land managers for determining optimum management strategies, and rotation age in their market place. These models predict yields to which current stumpage values can be applied to estimate the economic worth of a particular management regime. However, the results obtained are the best management strategies for the seller of stumpage. The results may not be appropriate for an organization that owns both the manufacturing facility and the land. To find the most desirable rotation age, the yield model must be capable of estimating good measures of final product yields such as dry weight of pulp, lineal feet of veneer (plys), and the size and grade distribution of lumber. Mill managers armed with a growth and yield model capable of accurately estimating the manufactured yields will be able to obtain better estimates of the true value of the land base and of the best management strategies for their mill mix. Decisions could be made to harvest or leave stands to optimize current or future yields, or the purchase price of stumpage could be based on expected product yields.

The Mississippi State University integrated loblolly pine growth and yield simulator has a dry weight pulp yield model fully embedded in the program and produces estimates comparable to those observed by industry. The downloadable simulator is available at http://cfr.msstate.edu/fwrc/software.htm (loblolly). We are now working on embedding a veneer yield model and a model to estimate the distribution of lumber by size and grade. When completed, the model will estimate expected manufactured yields for most mill configurations, allowing evaluation of forest stands from both the landowner and mill side perspective.

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