TAUYIELD: A STAND-LEVEL GROWTH AND YIELD MODEL FOR THINNED AND UNTHINNED LOBLOLLY PINE PLANTATIONS

Version 3.0

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Ralph L. Amateis

Philip J. Radtke

Harold E. Burkhart

Abstract. A stand-level growth and yield model for thinned and unthinned loblolly pine plantations was developed using data collected from permanent remeasurement plots throughout most of the natural range of the species. The model was constructed around three dynamic equations which reflect height-age, survival and basal area development in thinned and unthinned plantations. Modifier equations that adjust growth for particular site preparation and mid-rotation fertilization treatments were added. A yield prediction system apportions total yield and total number of trees surviving into diameter classes so that merchantable yields for a pulpwood management regime and an integrated pulpwood and sawtimber regime can be obtained. Performance of the component equations as well as the overall model was examined using independent data from thinned and unthinned stands. Test results indicate the model should provide reliable estimates of yields for many stand conditions and thinning and fertilization treatments.

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INTRODUCTION

Loblolly pine (*Pinus taeda* L.) is one of the most productive tree species in the southern United States. Wood produced from loblolly pine plantations is processed for pulp and paper products as well as sawn, peeled and chipped for construction material. Increasingly, plantations of loblolly pine are being intensively managed by applying silvicultural treatments to enhance their productivity. Important silvicultural tools available to managers include site preparation and mid-rotation fertilization and thinning. Chemical site preparation reduces competition for site resources resulting in improved growth of the pines. Mid-rotation fertilization accelerates stand growth while thinning provides an opportunity to obtain intermediate cash flows from wood harvested in thinning operations, improve the quality of the residual stand by removing slow-growing and damaged or diseased trees and shift future growth of the stand to the larger, better quality residual trees. Therefore, there is a need for growth and yield models which can reliably forecast future yields for intensively managed plantations.

In the early 1980s, Amateis et al. (1984) developed a stand-level growth and yield model for unthinned loblolly pine plantations based on initial measurements from a large region-wide set of permanent plots. Subsequently, the thinned and unthinned permanent plots established in 1980-1982 were remeasured. After four remeasurements, an enhanced model for thinned and unthinned plantations (Amateis et al. 1996[1]) called TAUYIELD was developed. Version 2.0 incorporated additional remeasurement data and more recently developed site index and tree survival functions. This version (3.0) includes new modifier functions for site preparation and mid-rotation fertilization. The description that follows includes details about original work done on TAUYIELD and version 2.0 along with documentation of the added modifier functions.

The objective of TAUYIELD is to produce growth and yield estimates which can be used for a variety of purposes including inventory updating, harvest scheduling, predicting wood yields for different stand conditions and evaluating the effects of thinning on stand dynamics and wood production. In order to accomplish this objective, two criteria were established to guide the model development process. The first was that predictive ability of the model would be of primary concern. That is, both individual component equations and the model as a whole should predict well for the development and independent testing data available. The second criterion was that component equations and the overall model should reflect current understanding of how thinned and unthinned plantations grow and develop through time. Including such biological and physical precepts in the model development process increases the likelihood that the model will perform well for stand conditions outside the range of the data used to develop it. This makes the model more reliable when applied to other data and when extrapolated to conditions beyond those reflected in the development data. It also provides a more robust framework for any future enhancements such as the inclusion of other silvicultural treatments.

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[1] Amateis, R.L., P.J. Radtke and H.E. Burkhart. 1996. TAUYIELD: A stand-level growth and yield model for thinned and unthinned loblolly pine plantations. Virginia Polytechnic Institute and State University. 42p.

The following sections summarize data sources, modeling rationale and model performance for version 3.0 of TAUYIELD, a stand-level growth and yield model for loblolly pine plantations under intensive management.

DATA

Several sources of data were used for model development and testing. The following sections summarize the stand characteristics associated with each.

Unthinned Coastal Plain

Stand data were available from loblolly pine plantations established on cutover sites in the Coastal Plain areas of Alabama, Florida, Georgia, North Carolina and South Carolina. Seven hundred twenty nine permanent remeasurement plots were established in these plantations at age two and remeasurements occurred at three-year intervals to age 14, 17 or, in some cases, to age 20.

Site preparation methods prior to plantation establishment consisted primarily of chop, burn, disk, bed, KG or some combination of these treatments. A general soil drainage class (poor, moderately well or excessive) was known for each site. Site index values averaged 65 feet (std. dev. = 13.0 feet). Table 1 presents average survival and basal area values for selected ages in the data set.

Table 1. Stand summary statistics for unthinned Coastal Plain data at ages 2, 8 and 14 (standard deviations in parentheses).

Variable	Age		
	2 (n=831)	8 (n=722)	14 (n=116)
Number surviving per acre	548 (310)	472 (277)	378 (252)
Basal area (sq. ft./ac.)	9.2 (11.4)	37.3 (25.7)	98.0 (46.6)

Thinned and unthinned region-wide

Stand data were available from loblolly pine plantations established on cutover sites from much of the natural range of the species. One hundred eighty-six plot locations were established during 1980-1982 dormant seasons in 8- to 25-year-old (mean=15) plantations in the southern Coastal Plain and Piedmont. Site and stand conditions at plot establishment for these locations were summarized by Burkhart et al. (1985). At each location, three plots, comparable in initial site index, number of trees and basal area per acre, were established: (1) an unthinned control plot, (2) a lightly thinned plot from which approximately one-third of the basal area was removed, and, (3) a heavily thinned plot from which approximately one-half of the basal area was removed. Thinnings were primarily from below removing smaller, poorly formed and slower growing trees. However, the considerations of spacing and stem quality dictated the removal, in some cases, of selected larger trees.

Five measurements, one taken at plot establishment and four subsequent remeasurements, were completed with a measurement interval of three years. While some plots were abandoned during this period due to heavy insect attacks, hurricane damage, or other problems, observations over the 12-year period were obtained for most of the plots. One site index value was determined for each plot using the measurement closest to index age (25 years). Dominant height was defined as the average height of the dominant and codominant trees. The site index equation from Diéguez-Aranda et al. (2006), which was developed from these data and an additional three remeasurements, was used to compute site index. Site index ranged from 40 to 85 feet (mean = 60; std. dev. = 8.5). Table 2 summarizes other pertinent stand conditions for these plots at establishment and twelve years later.

Table 2. Summary statistics of plot characteristics for unthinned, light-thin and heavy-thin Coastal Plain and Piedmont plots at establishment and at the fourth remeasurement.

	Unthinned		Light-thin		Heavy-thin	
Variable	Establishment	12 yrs	Establishment	12 yrs	Establishment	12-yrs
Age (years)	15 (4)	27 (4)	15 (4)	27 (4)	15 (4)	27 (4)
Trees/ac.	567 (137)	440 (105)	338 (77)	311 (69)	257 (63)	241 (59)
Basal area/ac	110 (35)	151 (28)	77 (25)	127 (23)	63 (21)	113 (23)
Percent basal area left	---	---	0.73 (0.07)	---	0.59 (0.08)	---

Thinned-stand data sets

Three small thinned-stand data sets were available for testing basal area and survival predictions from the model and for examining basic stand development relationships. The first data set consisted of nineteen operationally thinned plots in the Coastal Plain area of Virginia. All plots received a heavy thinning from below at age 20 or 21. Table 3 summarizes the pre- and post-thinning stand conditions as well as stand conditions five years after thinning.

Table 3. Stand summary of mean conditions (standard deviations in parentheses) at plot establishment and five years later for nineteen operationally thinned plots in the Virginia Coastal Plain.

Variable	Before thin	After thin	Five years later
Site index (ft)	57.5 (3.3)	---	---
Basal area (sq.ft/ac)	126.9 (19.2)	60.8 (12.7)	81.5 (17.6)
Number trees/ac	528 (65)	194 (36)	194 (36)

A second small data set consisted of eighteen paired plots, half of which were unthinned and the other half thinned to a residual basal area close to that of the unthinned plots. Thinnings were from below at ages 18 or 23 and the plots were measured five years later. These plots, discussed by Bower and Baldwin (1993) are located near Merryville, Louisiana. Table 4 summarizes these data.

Table 4. Summary statistics of mean conditions (standard deviations in parentheses) for eighteen paired thinned and unthinned plots near Merryville, Louisiana.

	Unthinned		Thinned		
Variable	Establishment	Five years	Before thin	After thin	Five years
Site index (ft)	65 (2.8)	---	67 (3.2)	---	---
Number trees/ac	348 (90)	317 (71)	---	321 (62)	302 (56)
Basal area (sq. ft/ac)	116.2 (12.9)	142.4 (12.0)	131.9 (15.8)	113.1 (8.5)	141.1 (9.5)

A third small data set consisting of eight tenth-acre plots, called the "Heywood Lease" study (Xydias, et al., 1982) was also available for model evaluation. At one location, there were two replications each containing an unthinned plot, a plot thinned to 300 trees per acre, a plot thinned to 200 trees per acre and a plot thinned to 100 trees per acre. Plots were established at age eleven and the site index was about 85ft. Remeasurements were collected at ages 12, 13, 15, 16, 17, 20, 21, 22, 24, 25, 26, 27, and 29. Because the plot size was rather small and the two replications were quite similar, the two plots for each treatment were combined into one fifth-acre plot. Table 5 provides a summary of basal area and survival for each treatment at selected ages.

Although limited in size and scope, these data sets provided useful insights into how thinned and unthinned stands develop with regard to basal area and survival. They were also used as confirmation data sets to test models.

Table 5. Basal area and survival for each of four thinning treatments at plot establishment, five years, ten years and eighteen years after treatment for the Heywood Lease data.

	Treatment			
Variable	Unthinned	300 trees/ac	200 trees/ac	100 trees/ac
Number trees/ac				
Before thin	580	594	623	568
After thin	580	300	195	100
Age 16	475	290	195	100
Age 21	375	265	190	100
Age 29	275	250	190	100
Basal area (sq.ft/ac)				
Before thin	167	169	172	160
After thin	167	109	74	41
Age 16	200	141	108	71
Age 21	207	158	132	97
Age 29	207	191	176	138

MODEL DEVELOPMENT

This section provides a description of all component equations used in TAUYIELD and how each was developed. There are two subsections. The first describes the dynamic equations needed to project three critical stand parameters through time: dominant height, survival and basal area. The second section describes the yield prediction system for the model.

PROJECTION EQUATIONS

TAUYIELD was developed around three dynamic equations that project stand attributes into the future: height-age (site index), survival and basal area projection. Analyses of the region-wide thinning study data indicated that thinning affected all three of these dynamic stand attributes. The impact on dominant height was, however, minor (Sharma et al. 2006) so it was not included in the TAUYIELD system. Thinning impact was included in the new survival function, as indicated in a subsequent section. The effect of thinning on basal area development gradually increased from time of treatment to some maximum and then gradually diminished over time. Therefore, the thinning response function developed by Liu et al. (1995) was incorporated into the basal area projection equation of the system. The general form of the thinning response function is:

$$T = \left(\frac{G_a}{G_b} \right)^{\frac{r\,[-(A - TA)^2 + k\,(A - TA)]}{A^2}} \tag{1}$$

where:

T	=	thinning response
G_a, G_b	=	stand basal area after and before thinning, respectively
A	=	stand age
TA	=	age of thinning
r, k	=	parameters to be estimated

Equation (1) has certain desirable biological properties. The first is that when no thinning has occurred, the before to after thinning basal area ratio is 1 which means T has no effect on the equation of which it is a part. Second, at time of thinning the response is also conditioned to be 1 which means there is no immediate response at the time of thinning. Third, response to thinning begins at zero and, depending on the magnitudes and signs of r and k, affects the equation into which it has been incorporated to an increasing degree up to some maximum and then diminishes over time. The duration of thinning response (in years) is determined by the value of the duration parameter, k. The rate parameter, r, is dimensionless and along with G_a , G_b, A and TA defines the shape of the response function. The first derivative of the exponential part of Equation (1) with respect to A-TA, the time elapsed since thinning, indicates that the maximum thinning response will occur at $\frac{k\,TA}{k + 2\,TA}$ years after the thinning. Thus, age of maximum response depends on the age of the stand at time of thinning and the value of k. The following sections describe the development and evaluation of each of the dynamic component equations in TAUYIELD.

Dominant height / site index

An appropriate dominant height/site index equation is a central component equation of most growth and yield models. The site index equation in version 1.0 of TAUYIELD was based on a model developed by Amateis and Burkhart (1985) and fitted in its untransformed configuration (Cao, 1993). Subsequent work by Diéguez-Aranda et al. (2006) led to improved representation of dominant height development in loblolly pine plantations. Consequently, the function of Diéguez-Aranda et al. (2006), which follows, was incorporated into subsequent TAUYIELD versions:

$$Y = \frac{85.75 + X_0}{1 + \left(4474/X_0\right)t^{-1.107}} \tag{2}$$

where Y_0 and t_0 in the following expression represent the predictor height (ft) and age (yrs), Y is the predicted height at age t, and

$$X_0 = \tfrac{1}{2}\left(Y_0 - 85.75 + \sqrt{\left(Y_0 - 85.75\right)^2 + 4 \times 4474 Y_0 t_0^{-1.107}} \right)$$

To estimate the dominant height (Y) of a stand for some desired age (t), given site index (S) and its associated base age (t_s), substitute S for Y_0 and t_S for t_0. Similarly, to estimate site index at some chosen base age, given stand height and age, substitute S for Y and t_S for t. Site index in TAUYIELD uses an index age of 25 years.

Survival

The second dynamic component of TAUYIELD is an appropriate set of survival equations which reflect survival patterns over the entire life of a plantation. In the original version of TAUYIELD, survival was modeled using three distinct patterns during the life of a plantation. When developing subsequent versions of the model, survival was represented by a single equation fitted to the regionwide thinning study data. The resultant equation[2] applied to thinned as well as unthinned stands:

$$N_2 = \left[N_1^{-1.2681} + 0.000000005137 \times I_{ba} \times \left(\frac{S}{100} \right)^{1.9925} \left(A_2^{3.3912} - A_1^{3.3912} \right) \right]^{\frac{1}{-1.2681}} \tag{3}$$

where:

- N_1 = number of trees per acre at age A_2,
- N_2 = number of trees per acre at age A_2 ($N_2 \le N_1$)
- S = site index, base age 25 years, in feet
- I_{ba} = The ratio of basal area after thinning to basal area before thinning (BA_a / BA_b). For unthinned stands I_{ba} is set to 1.0

The square root of the mean square error for Equation (3) is 15.03 and the pseudo R^2 value is 0.988. Thinned stands exhibit slightly less mortality than unthinned stand of the same stocking, age, and site index.

Basal area

In order to develop an appropriate basal area projection equation, the relationship between basal area growth and certain stand characteristics was evaluated. Segregation of the unthinned plots in the region-wide thinning study data into site classes indicated that stands established on better sites produced more basal area at a faster rate than stands on poorer sites. Table 6 summarizes the basal area development for the unthinned plots with average site index (between 55 and 65) by 5-year age increments centered at 10, 15, 20, 25, 30 and 35.

[2] Developed in 2013 as part of a Ph.D. dissertation by Nabin Gyawali.

Table 6. Simple statistics for basal area (sq ft/ac) by age for the unthinned plots with an average site index (60 ft).

Age	Mean	Std. Dev.	Minimum	Maximum	Number plots
10	85.0	29.4	55.4	128.5	5
15	119.3	23.8	70.6	176.5	55
20	140.0	21.7	101.1	191.8	88
25	152.2	24.2	82.7	212.1	94
30	159.9	21.4	117.5	200.8	32
35	149.2	21.8	125.2	176.3	6

Table 6 shows increasing basal area to about age 30 and then a subsequent downturn. Only six plots have reached age 35 so it is difficult to determine the reliability of the downturn. However, other researchers have noted its occurrence especially in denser stands (e.g. Hafley, et al., 1982; Harrison and Daniels, 1988).

Comparing the mean tree growth rates for the unthinned, light-thinned and heavy-thinned plots indicated that the relative rate of basal area production for thinned stands was greater than for unthinned stands, at least for some period of time following thinning. This finding was corroborated by the Merryville data in which plots thinned to the same basal area as unthinned plots grew faster in basal area for at least the first five years after thinning (Bower and Baldwin, 1993). Relative rates of basal area production on the Heywood Lease plots also show that basal area growth rates in thinned stands exceed those of unthinned stands, all else the same.

While thinning can increase basal area relative growth rates, thinning reduces the maximum basal area carrying capacity. The Heywood Lease data show that 18 years after thinning, the thinned plots show no sign of converging to the same maximum basal area level as the unthinned plots. For the region-wide thinning study, after 12 years, the thinned plots have not achieved the same basal areas as the unthinned plots and do not indicate they will do so at least for typical rotation ages. It seems that thinning hastens basal area development to an asymptotic maximum that is less than that for unthinned stands. This may be due to the fact that thinning disrupts the normal stand development process making less efficient use of the available growing space. By removing trees in the thinning operation, growing space once occupied by pines can now be utilized by encroaching hardwoods and other vegetation. Regression analyses of pine basal area growth on understory basal area indicated that for many of these cutover sites the understory basal area had a significant negative impact on overstory basal area growth. This was the case for both the thinned and unthinned plots.

With these relationships in mind, a simple growth function was selected as a base model and then modified to incorporate these observed relationships. This general approach has been used by other researchers (e.g. Clutter and Allison, 1974; Clutter and Jones, 1980; Harrison and Daniels, 1988). For our base model we selected the growth function derived by McDill and Amateis (1992):

$$Z_2 = \frac{M}{1 - \left[1 - \frac{M}{Z_1}\right]\left(\frac{A_1}{A_2}\right)^{a}} \tag{4}$$

where:

Z_1, Z_2	=	size attribute
A_1, A_2	=	age at time 1 and time 2
M	=	asymptotic maximum size parameter
a	=	dimensionless rate parameter

For our application, the size attribute selected for modeling was mean tree basal area. We incorporated site index into both the rate and asymptotic maximum parameter. Thus, basal area development on better sites will proceed at a faster rate to a greater asymptotic maximum than poorer sites. We incorporated the thinning response function into the model so that the rates of basal area production are modified by both the timing and intensity of thinning. This was done in such a way as to maintain the path invariance property of projection. Using dummy variables, we fit separate maximum basal area parameters to each of the thinning treatments. The light-thin and heavy-thin parameters were not significantly different from each other, but both were different from the unthinned maximum basal area parameter, which was significantly larger. For these data the basal area carrying capacity is not particularly sensitive to the timing or intensity of the thinning, but just to the fact that the stand has been thinned or not. The final basal area projection equation is:

$$G_2 = \frac{N_2 M}{1 - \left[1 - \frac{N_1 M}{G_1}\right]\left(\frac{A_1 T_1}{A_2 T_2}\right)^{a}} \tag{5}$$

where:

$$M = \mathrm{b}_1\left(\frac{G_a}{G_b}\right)\ln S$$

$$a = \mathrm{b}_2\left(\ln S\right)^{\mathrm{b}_3}$$

$$T_1 = \left(\frac{G_a}{G_b}\right)^{\frac{-\mathrm{r}\left[\left(A_1 - TA\right)^2 + \mathrm{k}\left(A_1 - TA\right)\right]}{A_1^2}}$$

$$T_2 = \left(\frac{G_a}{G_b}\right)^{\frac{-\mathrm{r}\left[\left(A_2 - TA\right)^2 + \mathrm{k}\left(A_2 - TA\right)\right]}{A_2^2}}$$

and:

G_1, G_2	=	basal area (sq.ft/ac) at A_1 , A_2 , respectively
N_1, N_2	=	number trees/ac at A_1, A_2, respectively
G_a, G_b	=	basal area after and before thinning, respectively
S	=	site index (ft at age 25)
TA	=	thinning age
$b_1 - b_3, r, k$	=	parameters to be estimated

Equation (5) was fitted to the thinning study data and parameters were estimated using nonlinear least squares. Table 7 presents the parameter estimates and fit statistics.

Table 7. Parameter estimates and fit statistics for Equation (5) fitted to the thinning study data.

Parameter	Estimate	Asymptotic Std. Error
b_1	0.6579	0.0553
b_2	0.3346	0.0997
b_3	0.8710	0.2141
R	0.9121	0.1344
K	9.0648	1.7980

MSE = 23.2

Figure 1 shows the mean residuals by plot and time since thinning.

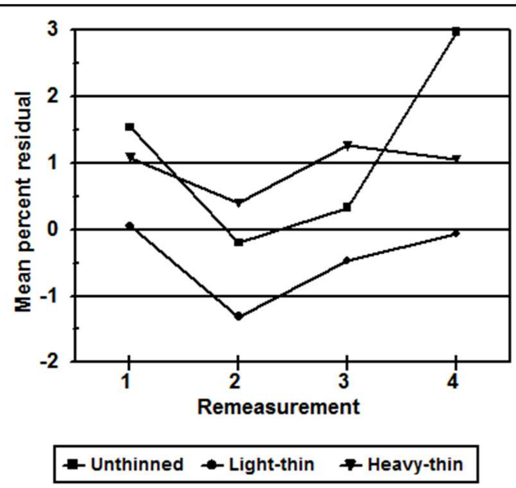

Fig. 1. Mean percent residual ((obs-pred)/obs*100) for Equation (5) fitted to the thinning study data by thinning treatment and time since thinning (remeasurement).

Equation (5) was tested against the Merryville data, the thinned Virginia Coastal Plain data, the unthinned Coastal Plain data and the Heywood Lease data. For the Merryville data, the average percent bias ((observed-predicted)/observed)*100) was 5.0 percent. For the thinned Virginia Coastal Plain data the average percent bias was 3.5 percent. For the unthinned Coastal Plain data the average percent bias was 7.4 percent and for the Heywood Lease plots the average percent bias was -9.0 percent. Figures 2a-2d show the predicted and observed basal area development for the four Heywood Lease plots. The general overprediction trend for these plots may be due to the uncertainty of the site index estimate for these plots.

In order to project stand basal area, it is necessary to provide TAUYIELD with an initial basal area. When one is not available, the following basal area prediction equations can be used:

$$\ln G = b_0 + b_1 (1/A) + b_2 (\ln N) + b_3 (\ln H) + b_4 (\ln S) + b_5 \left(\frac{N_t \ TA}{N_a \ A} \right) \tag{6}$$

$$\ln G = b_0 + b_1 (1/A) + b_2 (\ln N) + b_3 (\ln H) + b_4 (\ln S) + b_5 \left(\frac{G_t \ TA}{G_a \ A} \right) \tag{7}$$

where:

N_t	=	number of trees removed in the thinning operation
N_a	=	number of trees remaining after thinning
G_t	=	basal area removed in the thinning operation
$b_0 - b_5$	=	parameters to be estimated

and all other variables as previously defined. Equations (6) and (7) are similar in form to those presented by Pienaar and Shiver (1986) and can be used to initialize basal area for thinned or unthinned stand conditions. When the stand is unthinned, N_t is zero and the last term of the equation has no effect on the prediction of basal area. For a thinned stand, predictor variables include the age of thinning and a measure of thinning intensity in terms of percent of basal area or percent of trees removed in the thinning operation. As the time since thinning increases, the effect of thinning on basal area diminishes. Table 8 presents the parameter estimates and fit statistics for Equations (6) and (7).

Table 8. Parameter estimates and fit statistics for Equations (6) and (7) fitted to the thinning study data.

Parameter	Equation (6) Estimate (Std. Err.)	Equation (7) Estimate (Std. Err.)
b_0	-3.1166 (0.1479)	-3.2002 (0.1446)
b_1	-5.5462 (1.0438)	-5.6477 (1.0461)
b_2	0.5318 (0.0126)	0.5393 (0.0124)
b_3	0.7330 (0.0782)	0.7216 (0.0784)
b_4	0.5120 (0.0791)	0.5331 (0.0791)
b_5	-0.0663 (0.0117)	-0.0946 (0.0187)
	$R^2 = 0.85$ MSE = 0.0160	$R^2 = 0.85$ MSE = 0.0161

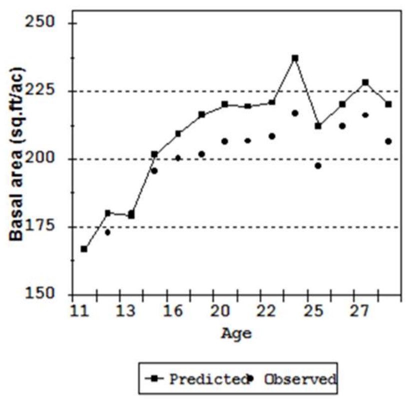

Fig. 2a. Observed and predicted basal area development for the unthinned Heywood Lease plot.

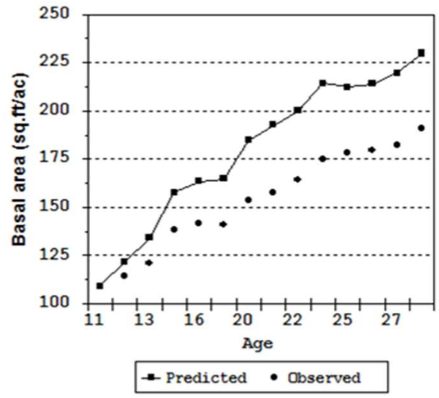

Fig. 2b. Observed and predicted basal area development for 300-trees per acre Heywood Lease plot.

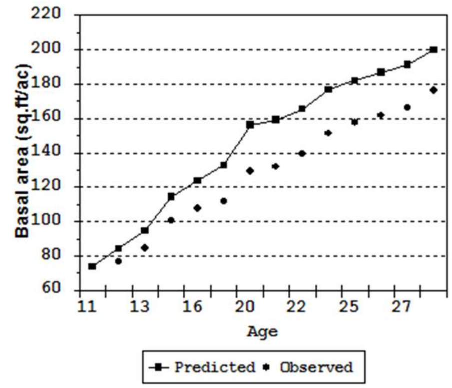

Fig. 2c. Observed and predicted basal area development for 200-trees per acre Heywood Lease plot.

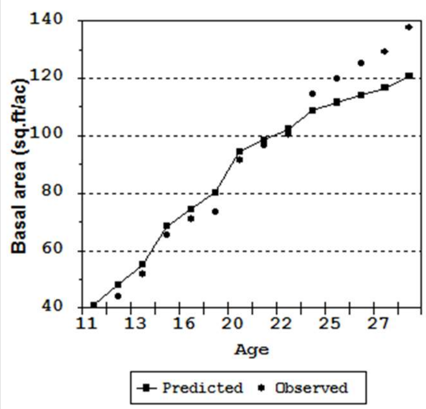

Fig. 2d. Observed and predicted basal area development for 100-trees per acre Heywood Lease plot.

YIELD PREDICTION

This section documents the yield prediction system developed for TAUYIELD, including results from investigations into yield relationships between thinned and unthinned stands as well as the development of component equations for the system.

Yield relationships

Total yields in cubic feet per acre were generated for each plot in the region-wide thinning study data using the tree volume equations developed from the same data and presented by Amateis and Burkhart (1987). Analyses of the data indicated that thinning has two major effects on the development of yield. The first is a negative effect on total cubic-foot yield production. That is, accelerated basal area growth of the residual stand does not compensate for the amount of lost productive capacity incurred by the thinning operation. At twelve years after thinning the standing yield on the thinned plots had not achieved that of the unthinned plots. (However, it is interesting to note that by twelve years after thinning the total production from the thinned plots which includes the volume harvested in the thin plus the standing volume has achieved the standing volume of the unthinned plots.) Figures 3 and 4 show cubic-foot volume outside bark growth over the twelve-year period for the unthinned, light-thinned and heavy-thinned plots.

The second important relationship is that thinning shifts the diameter distribution to the right by causing even the largest diameter classes to grow faster than their unthinned counterparts. Thus the percentage of merchantable yield is increased by thinning. Figure 5 shows the average maximum diameter growth over the twelve-year period for each thinning treatment.

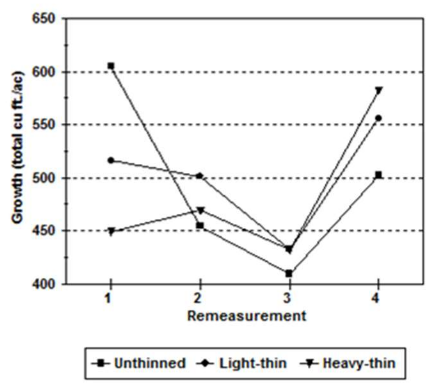

Fig. 3. Average total cubit foot volume growth by thinning treatment for each 3-year remeasurement period.

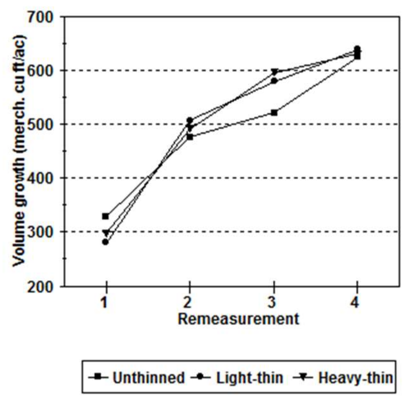

Fig. 4. Average cubic foot volume growth of the 8-inch class to a 6-inch top diameter by thinning treatment for each 3-year remeasurement period.

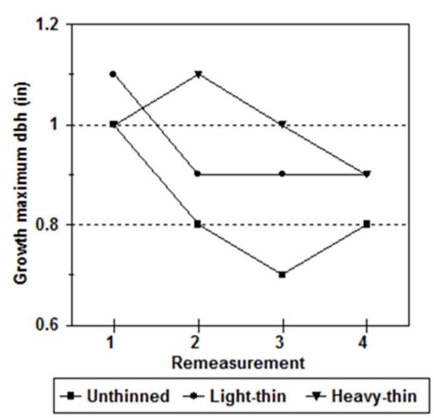

Fig. 5. Average growth of the maximum dbh class by thinning treatment for each 3-year remeasurement period.

Total yield prediction

In order to predict total cubic foot volume, a multiple linear regression equation was formulated:

$$\ln Y = b_0 + b_1(1/A) + b_2(\ln S) + b_3(H/A) + b_4(A \ln N) + b_5(\ln G) + b_6\left(\frac{G_t\ TA}{G_a\ A}\right) \tag{8}$$

where: $b_0 - b_6$ = parameters to be estimated

and all other variables as previously defined. Equation (8) is formulated such that when the stand is unthinned, G_t is zero and the last term of the equation has no effect on the prediction of volume. For a thinned stand, predictor variables include the age of thinning and a measure of thinning intensity in terms of percent of basal area removed in the thinning operation. As the time since thinning increases, the effect of thinning on volume diminishes. Table 9 presents the parameter estimates and fit statistics for Equation (8) fitted to the total inside and outside bark volume data. All parameter estimates were highly significant (Pr >0.0001). The large positive value of b_5 relative to the small positive value of b_6 ensures that total yield for unthinned stands will be greater than for thinned stands. The fact that b_6 is positive ensures that lightly thinned stands will have more volume than heavily thinned stands.

Table 9. Parameter estimates and fit statistics for Equation (8) fitted to the total inside and outside bark cubic foot volume data of the thinning study.

Parameter	Outside bark Estimate (Std. Err.)	Inside bark Estimate (Std. Err.)
b_0	1.15173 (0.0521)	0.98320 (0.05611)
b_1	-9.33466 (0.1480)	-13.011 (0.1594)
b_2	0.40538 (0.0156)	0.40357 (0.0168)
b_3	0.24032 (0.0067)	0.27825 (0.0072)
b_4	0.00321 (0.0001)	0.00251 (0.0001)
b_5	0.96176 (0.0042)	0.98736 (0.0045)
b_6	0.06322 (0.0041)	0.08764 (0.0044)
	R^2 = 0.99 MSE = 0.0009	R^2 = 0.99 MSE = 0.0011

Merchantable yield

In order to predict merchantable yield for any diameter class threshold or top diameter limit, a stand-level volume ratio equation was formulated (Amateis et al. 1986). The thinning response function (Equation 1) was incorporated into the equation in order to model the effect of thinning on the prediction of merchantable yield:

$$Y_m = Y\, e^{b_1 (t/\overline{D})^{b_2} + b_3 N^{b_4} (d/\overline{D})^{b_5 T}} \tag{9}$$

where:

Y_m	=	merchantable yield (cu ft./ac) for trees *d* inches and above to a *t* inch top diameter limit
Y	=	total yield (cu ft./ac)
N	=	number trees per acre
D	=	quadratic mean dbh (in)
d	=	top diameter limit (in)
t	=	threshold diameter limit (in)
T	=	thinning response function (Equation (1)): $T = \left(\frac{G_a}{G_b}\right)^{\frac{r[-(A-TA)^2 + k(A-TA)]}{A^2}}$
$b_1 - b_5, r, k$	=	parameters to be estimated

and all other variables are as previously defined.

Equation (9) is structured so that thinning affects the parameter b_5 causing the prediction of merchantable yield to be somewhat larger than for a corresponding unthinned stand. When there is no thinning, the b_5 parameter is unaltered. Equation (9) was fitted to the inside and outside bark merchantable yield data. Table 10 presents the parameter estimates and fit statistics for Equation (9).

For obtaining cordwood volume outside bark to a 4-inch outside bark top, the cubic feet of wood and bark per standard cord conversion factors of Burkhart et al. (1972) can be used. International 1/4-inch, Scribner and Doyle equations (Burkhart et al., 1987) were used to compute board-foot volumes by diameter class for the sawtimber quality trees greater than 7.5 inches dbh to a 6-inch top dib in the region-wide thinning study. Cubic foot volumes for the same trees were computed and the average ratio of board-foot to cubic foot volume outside bark by diameter class was obtained. These ratios allow conversion of cubic foot volumes to board-foot volumes by diameter class. Using this ratio method ensures that no matter how the stand is merchandised, the sum of the volume components will be equivalent to the total cubic foot yield production.

In a similar way, topwood cord volume for the sawtimber quality trees greater than 7.5 inches dbh was computed using the topwood prediction equation in Burkhart et al. (1972). Cubic foot volume between the 6-inch and 4-inch top diameters outside bark was computed and an average cubic-foot-to-cord conversion factor for topwood determined for each diameter class. Since wood is often sold to the mill by weight in many parts of the South, TAUYIELD 3.0 presents pulpwood and sawtimber yields in green tons using average conversion factors of 2.575 tons per cord and approximately 6 tons per MBF (Int ¼).

The proportion of pulpwood and sawtimber volume by diameter class was assumed to be the same as the proportion of trees in these product classes. Therefore, the product proportions of Burkhart and Bredenkamp (1989) can be applied. Table 11 presents the sawtimber product proportions and all volume conversion factors used in TAUYIELD.

Table 10. Parameter estimates and fit statistics for Equation (9) fitted to the merchantable inside and outside bark cubic foot volume data of the thinning study.

Parameter	Outside bark Estimate (Std. Err.)	Inside bark Estimate (Std. Err.)
b_1	-0.61101 (0.00399)	-0.64451 (0.00400)
b_2	3.37678 (0.02180)	3.31852 (0.02016)
b_3	-1.02117 (0.01580)	-1.11606 (0.01758)
b_4	-0.14372 (0.00268)	-0.16181 (0.00274)
b_5	5.55350 (0.01049)	5.58466 (0.01073)
r	-2.81786 (0.07767)	-2.74538 (0.07846)
k	20.6673 (0.29892)	20.79355 (0.31187)
	MSE = 29701	MSE = 20048

Table 11. Sawtimber proportions and product conversion factors by diameter class.

Dbh class	Cubic feet per cord	Topwood cubic feet per cord	Proportion sawtimber volume	Int 1/4 board-feet per cu. ft. ob	Scribner board-feet per cu. ft. ob	Doyle board-feet per cu.ft. ob	Tons per cord
5	84	0	0	0	0	0	2.575
6	85	0	0	0	0	0	2.575
7	87	0	0	0	0	0	2.575
8	90	54	0.488	2.63	2.47	2.35	2.575
9	91	57	0.726	3.25	3.07	2.39	2.575
10	92	61	0.837	3.72	3.49	2.45	2.575
11	93	64	0.900	4.08	3.78	2.59	2.575
12	94	67	0.937	4.36	3.97	2.81	2.575
13	95	70	0.960	4.58	4.09	3.06	2.575
14	95	73	0.975	4.76	4.17	3.33	2.575
15	95	74	0.984	4.89	4.22	3.58	2.575
16	95	77	1	5.03	4.27	3.91	2.575
17+	95	79	1	5.16	4.29	4.28	2.575

Number of trees
Most users of TAUYIELD will be primarily interested in estimates of yield. However, sometimes it is useful to know how the yield is distributed with regard to number of trees and basal area. Equation (10) allows portioning of the total number of trees across the diameter distribution:

$$N_m = N e^{-\Gamma^{(b_1 T/2)}(1+2/b_1 T)(d/\overline{D})^{b_1 T}} \qquad (10)$$

where:

N_m = trees per acre larger than *d* inches

Γ = gamma function

T = thinning response function (Equation (1)): $T = \left(\frac{G_a}{G_b}\right)^{\frac{r[-(A-TA)^2+k(A-TA)]}{A^2}}$

b_1, r, k = parameters to be estimated

and all other variables are as previously defined.

By including the thinning response function as a modifier of b_1, the shape of the diameter distribution can be altered to reflect the effect of thinning on the distribution of trees and basal area. Equation (10) is conditioned such that the sum of both the number of trees and the basal area across the diameter distribution will equal the total stand values. Table 12 shows the parameter estimates and fit statistics for Equation (10) fitted to the thinning study data.

Table 12. Parameter estimates and fit statistics for Equation (10) fitted to the diameter distribution data of the thinning study.

Parameter	Estimate (Std. Err.)
b_1	4.9022 (0.01066)
R	-4.3136 (0.18004)
K	18.2586 (0.42730)
	MSE = 214.7

Height prediction

Although height-diameter relationships are not utilized within the TAUYIELD framework for apportioning volumes by diameter class, users may wish to view heights by dbh class as part of stand and stock table output. The height model is:

$$h = b_1 H^{b_2} 10^{\left[\frac{b_3}{A}+\left(\frac{1}{D}-\frac{1}{D_{\max}}\right)\left(b_4+b_5\frac{\log_{10} N}{A}\right)\right]} \qquad (11)$$

where:

h	=	tree height (ft)
H	=	dominant stand height (ft)
D	=	tree dbh (in.)
D_{max}	=	maximum dbh (in.) in the stand
A	=	stand age
N	=	number of trees per acre
$b_1 - b_5$	=	parameters to be estimated

Table 13 presents parameter estimates and fit statistics for Equation (11).

Table 13. Parameter estimates and fit statistics for Equation (11) fitted to the total height data of the thinning study.

Parameter	Estimate (Std. Err.)
b_1	1.4504 (0.00965)
b_2	0.9366 (0.00141)
b_3	-0.4413 (0.01268)
b_4	-1.3504 (0.00788)
b_5	2.8095 (0.05485)
	MSE = 9.94

MODEL RELATIONSHIPS

Unthinned

Figures 6a - 6f present some basic unthinned stand development relationships in TAUYIELD Version 1.0 (these trends are the same in Version 3.0). In general stand developmental relationships proceed faster on higher sites planted at greater densities.

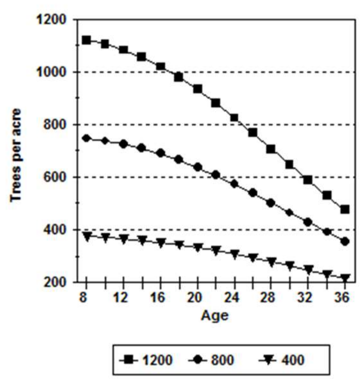

Fig. 6a. Survival trajectories for 1200, 800 and 400 trees per acre planted (site index 60).

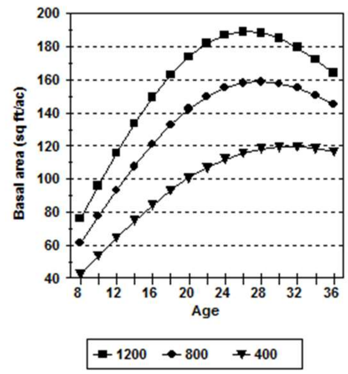

Fig. 6b. Basal area trajectories for 1200,800 and 400 trees per acre planted (site index 60).

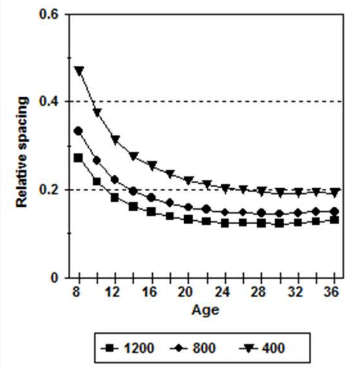

Fig. 6c. Relative spacing trajectories for 1200, 800 and 400 trees per acre planted (site index 60).

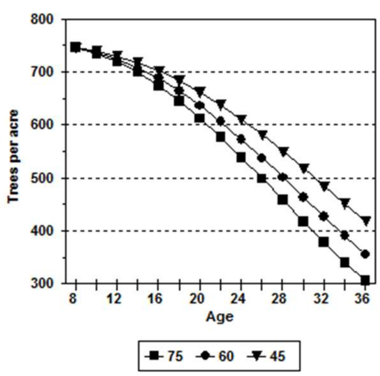

Fig. 6d. Survival trajectories for site index 75, 60 and 45 (800 trees per acre planted).

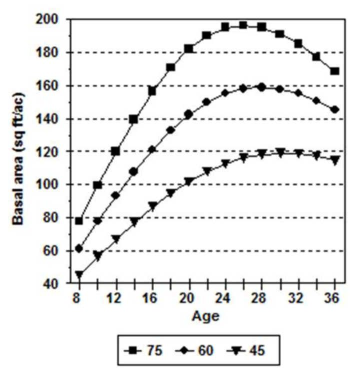

Fig. 6e. Basal area trajectories for site index 75, 60 and 45 (800 trees per acre planted).

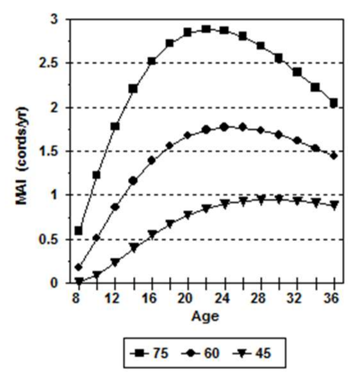

Fig 6f. Mean annual increment (cords/year) for site index 75, 60 and 45 (800 trees per acre planted).

Thinned-unthinned

Figures 7a - 7e compare some basic stand development relationships for the average unthinned, light-thinned and heavy-thinned stand in the region-wide plantation data set. At plot establishment, the average stand conditions were age 15, site index 60, 566 trees per acre and 110 square feet per acre of basal area. Following thinning, the average light-thinned conditions were 315 trees per acre and 80 square feet per acre of basal area. For the average heavy-thinned stand, the mean residual number of trees per acre was 238 and the mean residual basal area was 65 square feet per acre. These figures present projections to age 35 which, for the average stand, is 20 years following thinning.

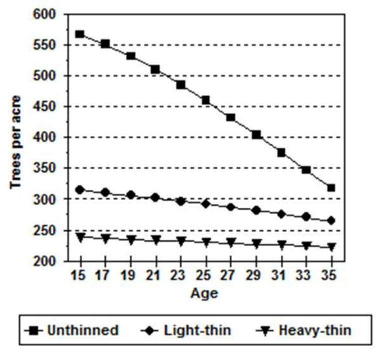

Fig. 7a. Survival trajectories (trees per acre) for the average unthinned, light-thin and heave-thin stand.

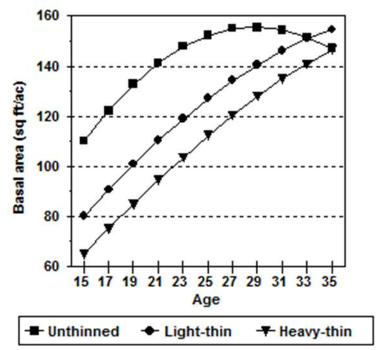

Fig. 7b. Basal area trajectories for the average unthinned, light-thin and heavy thin stand.

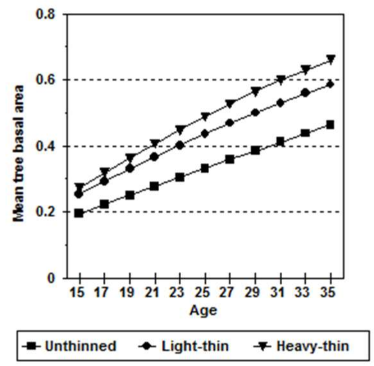

Fig. 7c. Mean tree basal area for the average unthinned, light-thin and heavy-thin stand.

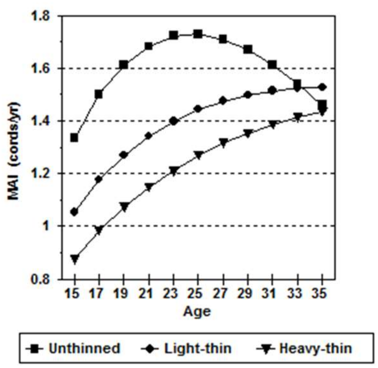

Fig. 7d. Mean annual increment (cords/year) for the average unthinned, light-thin and heavy-thin stand.

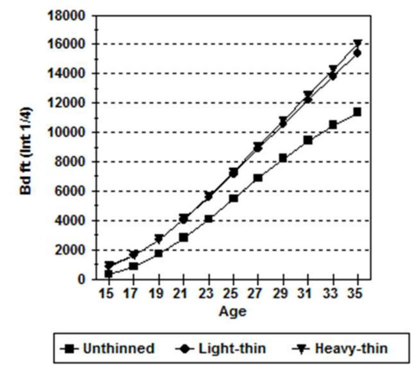

Fig. 7e. Board-foot production (Int. ¼) for the average unthinned, light-thin and heavy-thin stand.

Site Preparation and Fertilization Response Functions

In order to extend the usefulness of TAUYIELD to include intensive site preparation methods and mid-rotation fertilization, the response functions of Gyawali and Burkhart (2015) were incorporated into TAUYIELD.

Site Preparation

When "standard" or typical site preparation methods are used, Equation (12) is used to adjust the basal area development in TAUYIELD by multiplying basal area at each age by the value of Equation (12).

$$G_{control} = 15.8684\left(\frac{H}{A}\right)^{0.9204} N_p^{0.2974}\exp(-13.6056/A) \qquad (12)$$

When intensive woody chemical control is applied at time of plantation establishment then Equation (13) is used to adjust basal area:

$$G_{Woody} = 17.0806 \left(\frac{H}{A}\right)^{0.9204} N_p^{0.2974} \exp(-13.6056/A) \qquad (13)$$

When complete herbaceous and woody chemical controls are applied, Equation (14) is used:

$$G_{Herb\ and\ woody} = 19.6236 \left(\frac{H}{A}\right)^{0.9204} N_p^{0.2974} \exp(-13.6056/A) \qquad (14)$$

where A is stand age, H is dominant height and N_p is the number of trees planted in each equation. It can be seen that only the first parameter changes between the equations, ensuring that more intensive chemical treatments result in more pine basal area when other factors remain constant. If the higher levels of competition control are specified, the cost of site preparation at time of plantation establishment should be adjusted accordingly using the OPTIONS feature.

Fertilization

TAUYIELD version 3.0 incorporates the fertilization adjustment equations of Gyawali and Burkhart (2015) to account for the increased growth due to mid-rotation nitrogen and phosphorus treatments. Equation (15) is employed as a multiplier of the dominant height equation to reflect the effects of fertilization on height growth. Similarly, Equation (16) is used as a multiplier for the basal area growth equation.

$$Hd_{Fert} = 1 + [(0.000256 + 0.000192PHOS)NIT] \frac{2.9453}{7.7046} \left(\frac{YSF}{7.7046}\right)^{2.9453-} \exp[-\left(\frac{YSF}{7.7046}\right)^{2.9453}]$$
(15)

$$G_{Fert} = 1 + [(0.000738 + 0.000538PHOS)NIT] \frac{1}{6.9419} \exp[-\left(\frac{YSF}{6.9419}\right)] \qquad (16)$$

In both equations, NIT is the pounds per acre of elemental nitrogen, PHOS is treated as a “switch”: 1 if phosphorus is added with nitrogen, 0 otherwise, and YSF is years since treatment. These models exhibit greater growth response with greater amounts of NIT and when PHOS is included. The negative exponential response to YSF ensures that the effects of the treatment will diminish with time since application. Multiple fertilization treatments during the rotation are treated as additive. The cost of applying various levels of fertilizer can be adjusted using the OPTIONS feature

APPLYING TAUYIELD

Enhanced Genetics

TAUYIELD can be used to evaluate the feasibility of planting various types of genetically improved stock through making an appropriate adjustment to the specified site index and by modifying the plantation establishment cost accordingly.

TAUYIELD can be used for a variety of purposes including inventory updating, evaluating weed control, thinning and mid-rotation fertilization as silvicultural alternatives and as input to management decision-making. As such it is a tool available to a variety of forestry professionals, land managers and practitioners. The following should be kept in mind by those applying the model:

- The data used to develop all component equations for TAUYIELD come from loblolly pine plantations growing across much of the range of the species including both the coastal plain and piedmont physiographic regions. As such the model is a "stand average" model reflecting general growing conditions and yield relationships found in the data. Growth and yield relationships exhibited in TAUYIELD may, to a greater or lesser degree, mimic individual stands growing in specific localities.

- The data used to develop TAUYIELD reflect site preparation techniques common to southern plantation forestry during the late 1950s to early 1970s. On the average there was seventeen square feet of hardwood overstory and understory basal area in these plantations. Thus, projections from TAUYIELD will reflect these inherent site preparation and hardwood component characteristics.

- No plots from genetically improved plantations were used in the development of TAUYIELD. Application of TAUYIELD to these types of stands should not be made without appropriate alterations to component equations or input parameters.

- The light-thin and heavy-thin plots used in developing TAUYIELD received primarily selection thinnings from below with a few plots first receiving a row thinning to provide access followed by a selection thinning. Thinnings were, for the most part, accomplished by research personnel using chain saws. Trees were selected for removal based on size, vigor, quality and spacing. All plots were thinned once and allowed to grow for twelve years. Applying TAUYIELD to stands thinned under different criteria, stands thinned multiple times, or making projections beyond twelve years after thinning may not be appropriate.

- The response to competition control and fertilizer functions were adapted and incorporated using the models published by Gyawali and Burkhart (2015). Full details of the base data and the modeling methods used in developing these response functions can be found in the Canadian Journal of Forest Research 45:252-265.

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TAUYIELD 3.0 USER'S MANUAL

Preface

The equations that comprise TAUYIELD have been programmed into a Windows application for implementation with Windows operating systems. The TAUYIELD software is available for $195 by contacting:

Ralph L. Amateis
Department of Forest Resources and Environmental Conservation
Virginia Tech
310 West Campus Drive
Blacksburg, VA 24061
ralph@vt.edu

Most of the functionality of the TAUYIELD software follows that of other Windows applications and experienced users of Windows software should have no trouble implementing TAUYIELD. There are, however, nuances peculiar to this application for which additional explanation may be helpful.

Purpose of TAUYIELD

TAUYIELD is a computer program which can be used to predict the growth and yield of thinned or unthinned cutover, site-prepared loblolly pine plantations and do basic financial analyses based on those predictions. Predictions are obtained by choosing options from pop-up menus and responding to requests for stand level characteristics on a per acre basis. Results are displayed in terms of trees per acre, basal area and various volumes and green weight per acre by one-inch diameter at breast height (dbh) classes. The diameter distribution of the stand can be displayed as a 3D bar graph. At the end of a session, a stand summary and financial analysis of that stand summary can be displayed. If a printer is attached to the computer system, all output on the screen can be printed. Options are available to initialize a new plantation, initialize a thinned or unthinned plantation, thin a plantation using various methods, fertilize an existing stand, grow a stand and set values for merchantable limits and financial values. Using TAUYIELD, the user can grow and compare, within a short period of time, numerous thinning, competition control, and fertilization strategies for different stands.

Initializing a plantation

There are three initialization options presented on the toolbar: initializing an existing unthinned, existing thinned or new plantation. For each initialization option, a dialog box opens to accept necessary input from the user. For unthinned stands the basal area is optional input. An existing juvenile stand between the ages of 0 and 8 can be initialized with just the site index, age, and number of trees surviving. The juvenile stand is then advanced to age 8.

When the INITIALIZE EXISTING THINNED PLANTATION option is selected from the Initialize menu TAUYIELD prompts for the current age of the stand (or dominant height), the site index, the basal area, number of trees, the age of thinning, and percent of trees or basal area removed in the thinning operation.

The third option of the Initialize menu is to INITIALIZE A NEW PLANTATION. When this option is chosen TAUYIELD prompts for the number of trees planted, percent surviving at age 1, site index of the stand and whether chemical control of competing vegetation was part of the site preparation. The stand is then advanced to age 8.

Program limits

The stand age must be less than 41 years old. Site index can be between 39 and 95 feet (base age of 25). Basal area must be greater than 20 and less than 200 square feet per acre. Trees per acre must be greater than 80 and less than 1501. If data outside these limits are specified, an error message will appear. If an unrealistic combination of inputs is specified projections and predictions will be unrealistic. For some heavy low thins, illogical stand tables for the first few years after thinning can occur (when the total stand table basal area differs from the basal area projection equation value by more than 5 percent due to "ghosting" of thinned trees). In such cases, TAUYIELD will not display a stand table but instead notify the user to project to an older age. This anomaly will not occur for most typical low thinning regimes.

Merchantability limits

This option allows the user to specify a merchantable volume outside bark for a specified top diameter (ob) for pulpwood and threshold diameter limits for pulpwood and sawtimber.

Financial values

This option allows changing the interest rate, establishment cost, and product values for thinnings and harvest. These values are used to compute a financial analysis of the stand. To be considered a commercial pulpwood thinning, at least 4 cords per acre must be removed. Sawtimber removed at thinning must be at least 12 tons per acre. Otherwise, only pulpwood will be considered harvestable. When the Financial analysis option is checked, TAUYIELD displays the results of the financial analysis at harvest.

Varying competition control

TAUYIELD has three options for varying the level of competition control when initializing a new plantation. The default is no chemical control which represents a typical or “standard” level of control. Two levels of chemical control can be selected when intensive woody control is applied and when complete woody and herbaceous controls are applied. Adjustments to the total cost of plantation establishment (Options> Financial Values menu item) to account for higher levels of control must be made accordingly.

Genetic enhancements

TAUYIELD can accommodate the increased growth obtained from plantations established with advanced genetics through adjustments in the specified site index. Adjustments to the total cost of plantation establishment (Options> Financial Values menu item) to account for improved genetics must be made accordingly.

Midrotation fertilization

Midrotation N plus P fertilizers can be applied at any age during the rotation (Actions>Fertilize menu item). Multiple fertilizations are treated as additive. The cost of fertilization is inputted through the Options>Financial Values menu item.

Thinomatic thinning

The THINOMATIC thinning option will prompt for the basal area desired after thinning. The desired basal area must be greater than 20 square feet per acre and less than the current basal area. The THINOMATIC method removes trees according to the average pattern observed in certain types of operational thinnings where all diameter classes are subject to removals. The proportion of basal area removed in a 1-inch dbh class according to the thinomatic rule is given by the following equation (Burk et al. 1984):

$$P_i = \exp - 0.73148 * \left(D_i^2 / Q^2\right)^{1.45759}$$

where:

P_i = proportion of basal area to remove in class *i*

D_i = midpoint dbh of class *i*

Q = quadratic mean dbh before thinning

Basal area is removed according to the equation starting in the smallest dbh class and working upward until the desired residual basal area remains. If the entire dbh distribution is gone through without removing the required basal area, the remainder is obtained by removing all trees in the smallest dbh classes until the specified residual basal area is reached. Whenever only a portion of the trees in a dbh class are removed, the remaining trees are assumed to be uniformly distributed across the diameter class.

Row thinning

The ROW option will prompt for the desired basal area after thinning. The desired basal area must be greater than 20 square feet per acre and less than the current basal area. The ROW option removes a constant proportion from each dbh class. The proportion is equal to 1.0- (basal area after thinning/basal area before thinning). ***Note:*** *The thinning response function in TAUYIELD for pure row thinnings is set to 1.0. This means that growth after thinning for pure row thinnings will be the same as that of an unthinned plantation with reduced numbers of trees and basal area.*

Low thinning

There are two LOW thinning limit options: a DBH limit and a residual basal area limit. The SPECIFY DBH option allows specification of the threshold dbh. When specifying a threshold dbh, all trees below the threshold dbh will be removed. Specifying a threshold dbh that will leave less than 20 square feet of basal area causes the program not to remove all the trees below the threshold dbh. The program will leave at least 20 square feet of basal area. The SPECIFY BASAL AREA option prompts for a residual basal area in square feet after a low thinning. The basal area specified must be between 20 square feet and the current basal area shown on the status line. Trees will be removed starting at the smallest diameter class until the remaining basal area reaches what was specified.

Row/Low thinning

The ROW/LOW thinning option will prompt for the desired residual basal area after thinning and the percent of basal area to remove by row thinning. Basal area after thinning must be between 20 square feet and the current basal area shown on the status line. Percent basal area removed by row thinning must be between 1 and 100 percent.

Under the ROW/LOW thinning option, the basal area to be row thinned is removed first. This is done by computing basal area before and after row thinning and removing a constant proportion of trees from each dbh class as discussed under Row Thinning. The remainder of the basal area to be removed is obtained from the smallest dbh classes as discussed under Low Thinning. ***Note:*** *The thinning response function in TAUYIELD for ROW/LOW thinnings is determined from the LOW portion of the thinning. For example, if a stand with 120 square feet of basal area is to be thinned down to 70 square feet with 50 percent of the thinned basal area removed in the ROW thinning and 50 percent removed in the LOW thinning, then the after to before thinning basal area ratio for the response function would be 70/95 or 0.74.*

The ROW/LOW thinning option is used to obtain thinning results from below with a different stand structure than that provided by the THINOMATIC option. The ROW/LOW option differs from conducting a row followed by a low thinning in two respects. In the ROW/LOW option only one stock table is displayed. Using a row and then a low thinning two different stock tables will be displayed. Also, no provision is made to specify low thinning in terms of a threshold dbh class under the ROW/LOW option.

Growing a plantation

To grow a plantation, click the Grow toolbar button and specify a future age. A plantation must be initialized before it can be grown. The projected age must be greater than the current age and less than 41 years.

Harvesting a plantation

Following harvest (Actions>Harvest menu item), a stand history of management activity since initialization is presented including the age, action performed on the plantation, trees per acre, basal area and green tons by product. At the bottom of the table, the total volume removed is shown. In the Total Pulp Tons column only one product (pulpwood) is assumed of interest, whereas in the Pulp Tons and the Sawtimber Tons columns an integrated utilization for the two products is assumed. The minus signs indicate removals.

Financial analysis

When the INCLUDE FINANCIAL ANALYSIS option (Options>Include Financial Analysis menu item) has been checked, a financial analysis summary is displayed. The Financial Analysis summary displays any action that removed volume. It displays the age in which the action was performed, the action performed, the dollar value returned for pulpwood management, the dollar value returned for a pulpwood and sawtimber integrated management, the present value for pulpwood management and the present value for the pulpwood and sawtimber integrated management. Financial values (interest rate and dollar values for pulpwood tons and sawtimber tons) are set by the user under the Options main menu item. If the volume removed per acre is less than the minimum commercial volumes, the dollar value is zero. The present value sum for pulpwood management and integrated management are given based on separate products. The present value is used to determine the value today of some future return. The equation used for present value in TAUYIELD is shown below.

$$V_0 = V_n / (1+i)^n$$

V_0 = present value
V_n = value of product in the future
n = number of periods (years) in the future
i = interest rate per period (year)

In addition to present value (PV), a discounted cash flow analysis produces the net present value (NPV) for a single rotation for pulpwood utilization and for an integrated utilization of pulpwood and sawtimber. Net present values are a useful criterion for ranking management alternatives. In the NPV computation, establishment cost is subtracted from thinning revenue(s) (if any) plus final harvest revenue discounted to the time of stand establishment. Annual costs (e.g. taxes, boundary line maintenance, etc.) and potential annual revenue (e.g. hunting leases) are not included in the NPV computation. While a more complete financial analysis would be required for evaluating potential land purchases and other types of financial analyses, the simplified NPV computation can serve as a useful guide for those wishing to evaluate and rank management options. Users can modify establishment costs (as a single figure) to represent varying levels of expenses for site preparation and seedlings and stumpage values at thinning and at harvest can be varied to account for differences in stumpage revenues that might result from various silvicultural practices (including genetic improvement) and costs of thinning and harvest.

Output options

The TAUYIELD stand table output displays numbers of trees, average heights, basal area, and yield estimates per acre by one-inch diameter classes. The volume column shows total cubic feet outside bark. The three right-most columns display yield estimates in green tons. The total pulp tons column assumes the entire stand is merchandized for pulpwood. The integrated utilization columns of pulp tons and sawtimber tons assume the stand is merchandized into two mutually exclusive products: pulpwood and sawtimber. Recommended conversion factors for green tons to cord and International ¼ inch board foot volumes are also displayed.

Stand and stock table output values can be highlighted with the arrow keys or by dragging the mouse and then copied to the Windows clipboard. From the clipboard they can be pasted into other Windows applications such as spreadsheets or graphics packages. This facilitates further analyses of TAUYIELD simulation results.

Diameter bar graph

Placing a check mark beside this option displays a bar graph of the diameter distribution below the stand table.