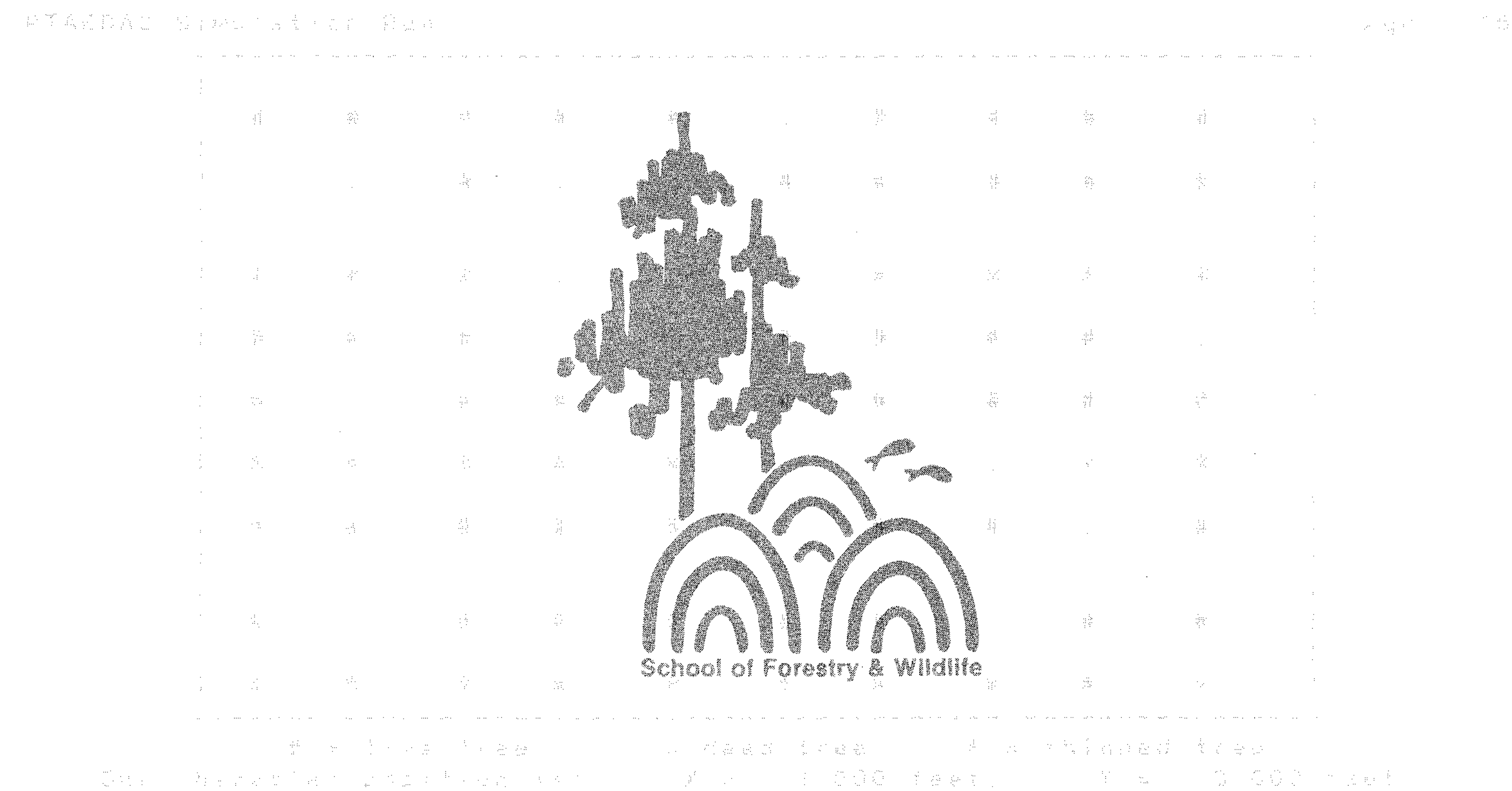
Simulation of Individual Tree Growth and Stand Development in Loblolly Pine Plantations on Cutover, Site-Prepared Areas



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School of Forestry and Wildlife Resources
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061

1987

SIMULATION OF INDIVIDUAL TREE GROWTH AND STAND DEVELOPMENT IN LOBLOLLY PINE PLANTATIONS ON CUTOVER, SITE-PREPARED AREAS

by

Harold E. Burkhart
Kenneth D. Farrar
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PREFACE

This bulletin presents a model to simulate individual tree growth and stand development in loblolly pine plantations on cutover, site-prepared areas. Those wishing to obtain a copy of the software for implementing this model on an IBM PC/XT/AT or compatible microcomputer using PC DOS or MS DOS 2.1 or later operating system should write to the authors at:

Biometrics Section
School of Forestry and Wildlife Resources
Virginia Polytechnic Institute and
State University
Blacksburg, Virginia 24061.

To defer the costs of postage and handling, a charge of $50.00 will be made for a diskette containing the compiled computer program. For $250.00, the source code is available. Checks should be made payable to "Department of Forestry, VPI and SU".

Although the software presented here has been extensively tested and checked for accuracy and, to the best of our knowledge, contains no errors, neither Virginia Polytechnic Institute and State University nor the authors claim any responsibility for any errors that do arise.

ABSTRACT

A forest stand simulator, PTAEDA2, was developed to model growth in loblolly pine (*Pinus taeda* L.) plantations on cutover, site-prepared areas. Individual trees were used as the basic growth units. In PTAEDA2, trees are assigned coordinate locations in a stand and 'grown' annually as a function of their size, the site quality, and the competition from neighbors. Growth increments are adjusted by stochastic elements representing genetic and microsite variability. Mortality is generated stochastically through Bernouli trials. Subroutines were developed to simulate the effects of hardwood competition, thinning, and fertilization on tree and stand development. Options for varying the spatial location of trees to mimic randomness in machine and hand planting operations are also included.

AUTHORS

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INTRODUCTION

Loblolly pine (*Pinus taeda* L.) is an important commercial species and much effort has been devoted to developing growth and yield models for various types of loblolly pine stands. Most of the past studies have been concerned with pure, even-aged natural stands or with plantations on abandoned agricultural land ('old fields'). The loblolly pine stand models developed have typically been of the 'whole stand' or 'diameter distribution' type (Burkhart *et al*. 1981).

The objective of the study reported here was to develop a stand model for loblolly pine plantations on cutover, site-prepared areas by using individual trees as the basic modeling unit. When developing this simulator, the basic model structure of Daniels and Burkhart (1975) was used. Components of the Daniels and Burkhart model (PTAEDA) for old-field loblolly pine plantations were estimated using a large data set from cutover, site-prepared plantations and a new software program (PTAEDA2) was written to implement the model. This bulletin is divided into two Parts. The first Part consists of a description of model development; the second Part serves as a user's guide for the model.

PART 1 -- MODEL DEVELOPMENT

DATA

Data were available from 186 plot locations established in cutover, site-prepared plantations throughout much of the natural range of loblolly pine. (For a more complete description of these sites, see Burkhart *et al*. 1985.) At each location, three plots were established. The three plots were required to be similar in site index, number of planted pine surviving and basal area to insure similar initial conditions. Then, no thin (control), light thin (approximately 30 percent of the basal area removed) and heavy thin (approximately 50 percent of the basal area removed) treatments were randomly assigned to the plots.

Prior to thinning, all trees were tagged, measured and their locations mapped. Tree measurements included dbh, total height and height to base of live crown. Besides the planted pine component, volunteer pines and hardwoods competing with the planted pines in the main canopy were also tagged, measured and mapped.

The thinning treatments applied to the lightly thinned and heavily thinned plots were primarily a low thinning such as might be accomplished under operational conditions. In some cases, occasional rows were removed to provide access to remaining trees. Tree removal was primarily based on size; however, larger diseased or poorly formed trees were also removed and spatial distribution of the residual stand was considered. Hardwoods were removed only when they would be removed operationally to provide access to a pine. That is, an effort was made to avoid confounding release from hardwood competition with thinning.

The three plots at each location were remeasured three years after establishment. Remeasurement data included dbh, total height and height to base of live crown. Mortality and ingrowth were also recorded. Thus, growth data for the unthinned condition as well as for the first three years after thinning were available for analyses. Table 1 summarizes the tree and stand characteristics for the unthinned control at time of plot establishment and at remeasurement.

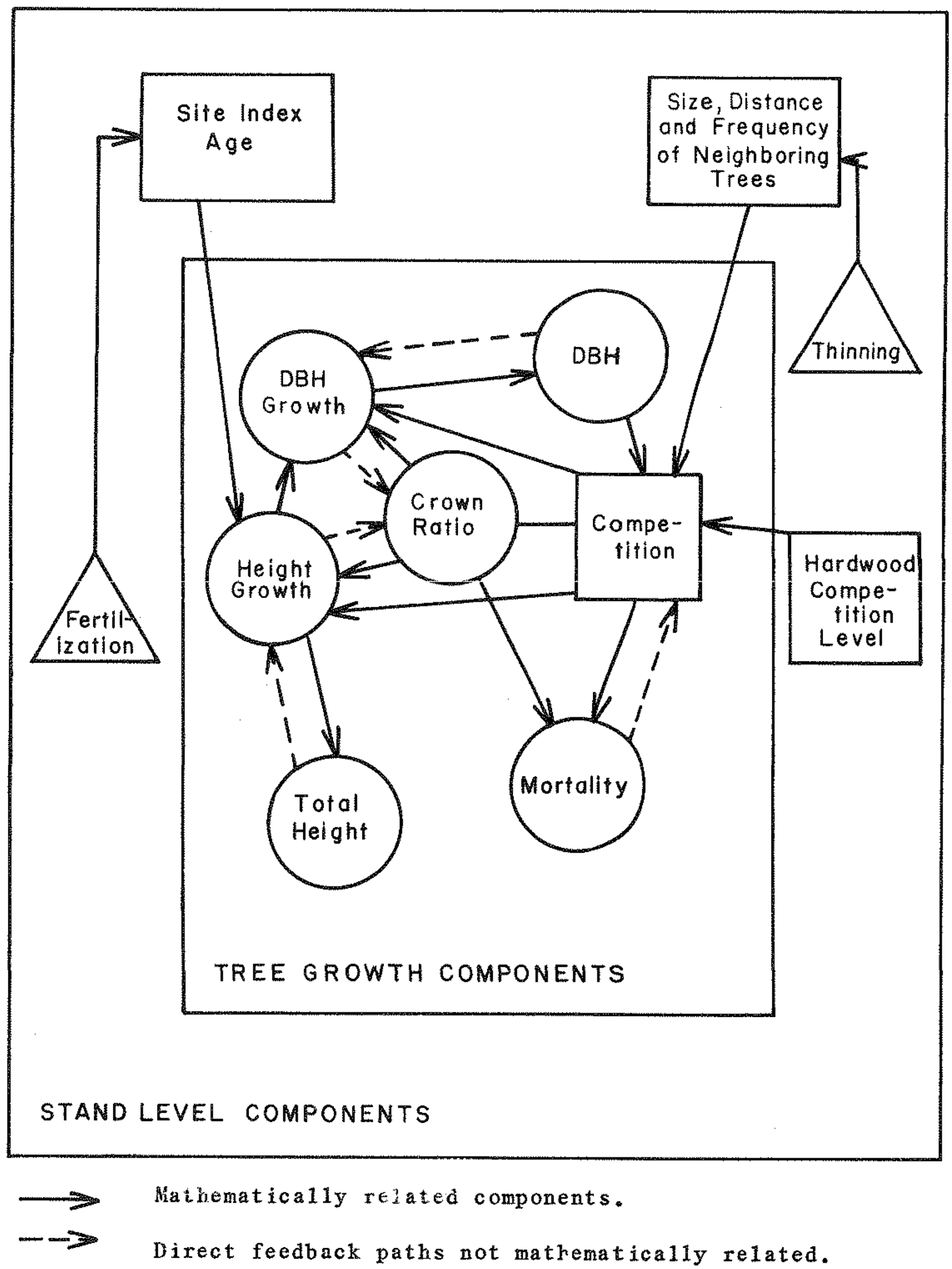
It was decided to use only the unthinned data for developing the growth relationships in PTAEDA2 for several reasons. First, with only one three year remeasurement period immediately after thinning it was difficult to determine what the longer term growth relationships for trees in thinned stands would be. Second, the growth equations fitted to the unthinned trees did not greatly underpredict tree growth on the thinned plots for the first three years after thinning. Finally, the predicted growth relationships exhibited by PTAEDA2 for thinned stands appear logical even though all coefficients were estimated using tree data from unthinned plots. This general procedure is the same as that followed by Daniels and Burkhart (1975) in the original version of PTAEDA. That is, estimates of response to thinning follow from the inherent structure and dynamics of the model even though all coefficients have been estimated using data from unthinned plots.

MODEL CONSTRUCTION

The stand model for loblolly pine plantations on cutover sites is similar in logic and structure to its predecessor PTAEDA (Daniels and Burkhart 1975). The two main subsystems in PTAEDA2 deal with the generation of an initial, pre-competitive stand and the growth and dynamics of that stand. Management subroutines were added to this framework to adjust program parameters for simulation of treated stands. The input and output routines add flexibility to the practical use of the simulator. Figure 1 is a schematic diagram showing the relevant entities in the model.

Table 1. Summary statistics for the 186 control plots at time of plot establishment and at time of remeasurement.

	At Plot Establishment			At Remeasurement		
	Min.	Mean	Max.	Min.	Mean	Max.
<u>Stand Variables</u>						
Age	8	15.2	25	11	18.2	28
Number of planted loblolly surviving (trees/ac.)	270	570	1000	270	544	1000
Arithmetic mean dbh of planted loblolly (in.)	2.7	5.7	9.9	4.0	6.4	10.6
Total overstory basal area (sq.ft./ac.-all tagged trees)	24.3	112.1	234.5	50.9	130.0	236.0
Planted loblolly basal area (sq.ft./ac.)	21.7	107.3	232.5	45.6	124.3	233.9
Volume planted loblolly (cu.ft./ac. outside bark)	215.7	2168.0	7765.4	556.2	2851.0	8596.3
Site index	37.9	61.8	90.4			
<u>Tree Variables</u>						
DBH (in.)	0.5	5.6	14.1	0.7	6.2	14.9
Total height (ft.)	5.0	37.5	80.0	8.0	43.2	86.0
Crown ratio	0.0	0.44	0.94	0.0	0.40	0.93



Mathematically related components.

Direct feedback paths not mathematically related.

Figure 1. Schematic diagram showing relationships between tree and stand components for a simulation model (PTAEDA2) of loblolly pine growth.

Additional subprograms (not shown) generate uniform, standard normal, and Weibull distributed random variates.

Initial Stand Generation

Rectangular spatial patterns in PTAEDA2 are controlled by subroutine PLANT in which a number of planting options were incorporated. A user may specify the distance between trees and between rows in a conventional manner (e.g. 6' x 8', 6' x 12') and enter ''0'' as the number of trees allowing the program to compute the planted number of trees. Alternatively, the number of trees may be specified along with the ratio of planting distance to row width (e.g. 3:4, 1:2). If this ratio is omitted, square spacing is assumed.

In addition, a provision was included which computes initial planting parameters from the surviving number of trees, age, and spacing ratios of existing stands. This provision was accomplished by solving for trees planted in the loblolly pine survival function presented by Feduccia et al. (1979) for cutover sites:

$$\log(TP/TS) = A(0.0135 \log TP + 0.0006HD - 0.0084\sqrt{HD})$$

where TP = number of trees planted
TS = number of trees surviving
A = stand age (years)
HD = average height of the dominant stand (ft.)
log = logarithm base 10.

From this information a plot of n x n dimension is generated. A fixed number of trees was chosen rather than a fixed plot size so that, in effect, plot size would increase with decreasing density. The default condition is 15 rows of 15 trees each but the user can specify anything from 5 x 5 to 20 x 20.

From this point, subroutine JUV advances the juvenile stand to an age where intraspecific competition begins. It was desired to bypass annual growth calculations in this juvenile period since 1) there are little data available with which to model growth in young stands; 2) instraspecific competition in such young stands is believed to be negligible; and 3) added calculations and computer time cannot be justified by more reliable estimates.

The age at which intraspecific competition begins was investigated by equating a diameter equation for open-grown trees and one for stand-grown trees fitted to the cutover-site data. This method, which is essentially the same as that used in the original version of PTAEDA, produced reasonable results (typical estimates of the age of onset of intraspecific competition were 6-8 years). However, subsequent investigations showed that there was no improvement in estimating plot yields when the age for switching from the juvenile to the stand dynamics subsystems was used as opposed to changing at an arbitrary age of 8 years (the youngest age in the tree growth data set). Thus, because it is simpler and more straightforward to use a fixed age, the juvenile phase always ends at age 8; the ninth growing season and beyond are predicted using growth and dynamics equations estimated from the cutover-site data.

At age 8 (i.e., after 8 growing seasons) the predicted juvenile mortality is assigned at random. Individual tree dimensions are then generated for the residual stand.

Diameter at breast height is generated from a two parameter Weibull distribution with a cumulative distribution function (CDF) as follows:

$$F(y) = 1 - e^{-ay^{b}} \qquad 0 < y < \infty$$

The inversion technique was used for generating random variates from this distribution. Parameters a and b are estimated from minimum and average DBH equations fitted to the younger aged (less than 13 years) cutover-site data as follows (Strub and Burkhart 1974):

$$b = \frac{\ln(TS/10)}{\ln DAVE - \ln DMIN}$$

$$a = \left[\frac{(1 + 1/b)}{DAVE}\right]^{b}$$

where DMIN = minimum DBH (inches)
DAVE = average DBH (inches)
TS = surviving number of trees per acre
ln = logarithm base e.

DMIN and DAVE are predicted from stand age, HD, and TS.

Height is generated for each tree based on a prediction equation involving DBH, HD, TS, and age. Crown length is then computed from total height and a crown ratio equation developed by Dyer and Burkhart (1987). Table 2 provides a summary of all equations used in generating the initial stand.

The juvenile stand and stock table at age eight can be obtained as optional output from PTAEDA2. It is shown once to the user prior to entering the individual tree growth simulation phase.

<u>Competition Index</u>

The competition index used in PTAEDA2 is the same as that applied by Daniels and Burkhart (1975):

$$CI_i = \sum_{j=1}^{n} (D_j/D_i)/DIST_{ij}$$

where D = DBH
DIST = distance between subject tree i and j^{th} competitor
CI_i = Competition Index of the i^{th} tree
n = the number of neighbors with a BAF 10 'sweep' centered at the subject tree.

Table 2. Equations used in the juvenile growth subroutine (JUV) of PTAEDA2, a tree and stand growth simulator of loblolly pine.

Equation*	R^2	$S_{y.x}$	Source
$D_O = -2.422297+0.286583HD+0.209472A$	0.92	2.14	Strub *et al.* 1975
$\ln(HD) = \ln(SI)(25/A)^{-0.02205} e^{-2.83285(A^{-1}-25^{-1})}$	0.82	4.66	Cutover-site data
$\log(TP/TS) = A(0.0135 \log TP + 0.0006HD-0.0084 \sqrt{HD})$	0.81	0.076	Feduccia *et al.* 1979
$DMIN = -0.19744+0.02735HD+14.5622\ HD/TS$	0.38	0.541	Cutover-site data
$DMIN_{HW} = -0.175362+0.026328HD+15.3232\ HD/TS -0.870907\ PHDWD$	0.39	0.544	Cutover-site data
$DAVE = 1.2951+0.10168HD-0.0000294\ A \cdot TS +11.4659\ HD/TS$	0.82	0.389	Cutover-site data
$DAVE_{HW} = 1.2262+0.09203HD+0.0000019\ A \cdot TS +15.6843\ HD/TS - 1.6757PHDWD$	0.83	0.382	Cutover-site data
$DMAX = 2.1753+0.14703HD+19.7457\ HD/TS$	0.83	0.557	Cutover-site data
$DMAX_{HW} = 2.2180+0.14504HD+21.2174\ HD/TS -1.6844\ PHDWD$	0.84	0.554	Cutover-site data
$\log(HD/H) = -0.0400+(D^{-1}-DMAX^{-1})(0.4284-0.4975\log(TS) +0.3638A^{-1}+1.0954\log(HD)$	0.65	0.041	Cutover-site data
$CR = 1-e^{(-1.35243-37.02600A^{-1})D/H}$	0.61	0.083	Dyer and Burkhart 1987
$CR_{HW} = 1-e^{(-1.43593-38.31743A^{-1})(D/H)(1-PHDWD)}$	0.59	0.084	Cutover-site data

*Where HD = average height of dominant and codominant stand (feet), TP = trees planted per acre, TS = trees surviving per acre, SI = site index (feet at base age 25), DMIN = minimum DBH (inches), DAVE = average DBH (inches), H = total tree height (feet), A = stand age (years), PHDWD = percent basal area of hardwoods, D = DBH, CR = crown ratio, DMAX = maximum DBH (inches), D_O = dbh of an open-grown tree, $DMIN_{HW}$ = minimum DBH (inches) when percent basal area of hardwoods is specified, $DAVE_{HW}$ = average DBH (inches) when percent basal area of hardwoods is specified, $DMAX_{HW}$ = maximum DBH (inches) when percent basal area of hardwoods is specified, CR_{HW} = crown ratio when percent basal area of hardwoods is specified.

Growth Relationships

After generation of the pre-competitive stand, competition is evaluated and trees are grown individually on an annual basis. In general, growth in height and diameter is assumed to follow some theoretical growth potential. An adjustment or reduction factor is applied to this potential increment based on a tree's competitive status and vigor, and a random component is then added representing microsite and/or genetic variability.

The potential height increment for each tree is considered to be the change in average height of the dominant and codominant trees, obtained as the first difference with respect to age. The site index model presented by Amateis and Burkhart (1985) was fitted to the remeasurement data from the permanent plots in cutover, site-prepared plantations to produce the following equation (Table 2):

$$\ln(HD) = \ln(SI)(25/A)^{-0.02205} e^{-2.83285(A^{-1}-25^{-1})}$$

where HD = average height of dominant and codominant stand (feet)
SI = site index base 25 (feet)
A = stand age (years)

A tree may grow more or less than this potential, depending on its individual attributes.

Past work has shown that, except in extreme cases, average dominant stand height is not strongly influenced by density. However, on an individual tree basis, competition from neighboring trees seems to affect a tree's realization of potential height increment. The competition index showed a significant correlation with observed height increment using the mapped stand data; accordingly, it was included in the adjustment factor for height growth.

Hatch (1971) pointed out the desirability of an index which reflects a tree's vigor as opposed to its competitive disadvantage. Crown ratio was considered to be a natural expression of a tree's photosynthetic potential and was used in the adjustment factor as an attribute positively related to realization of potential growth. But in construction of the adjustment factor it was found that crown ratio was also negatively related to tree growth in cases where it approached that of open grown trees. This is presumably related to the fairly well established phenomenon that on comparable sites height growth is generally somewhat less for open grown trees than for stand grown trees (Spurr 1952). Thus, the final equation form selected for the height increment when percent basal area of the hardwoods (PHDWD) is not specified was:

$$HIN = PHIN\,(b_1 + b_2\,CR^{b_3} e^{(-b_4 CI_p - b_5 CR)})$$

where HIN = height increment (ft.)
$PHIN$ = potential height increment (ft.)
CR = crown ratio
CI_p = pine competition index
b_1-b_5 = parameters estimated from the data.

The final equation form selected for the height increment when PHDWD is specified was:

$$HIN = PHIN\ (b_1 + b_2 CR^{b_3} e^{(-b_4 CI_p - b_5 MCI_{HW} - b_6 CR)})$$

where MCI_{HW} = mean competition index of hardwoods and all other variables are as previously defined.

The two equations for predicting HIN were fitted to the data using non-linear least squares (Table 3). As competition increases (of the pines and/or the hardwoods), the realization of potential height growth decreases. Holding the competition indexes constant, HIN gradually increases with increasing crown ratio, reaching a maximum when crown ratio is approximately 60 percent. Assuming residual variability in height growth is normally distributed, a random component is added to the final growth determinations with variance equal to the residual mean square from the fitted regression.

The maximum DBH attainable for an individual tree of given height and age was considered to be equal to that when open-grown. The equation used to describe this relationship in PTAEDA2 was the same as that applied by Daniels and Burkhart (1975) and is shown below:

$$D_0 = -2.422297 + 0.286583H + 0.209472A$$

$$R^2 = 0.9197 \qquad S_{y.x} = 2.14023$$

where D_0 = open-grown tree DBH (in.)

H = total tree height (ft.)
A = age from seed (years)

The first difference of this equation with respect to age represents a maximum potential diameter increment:

$$PDIN = 0.286583HIN + 0.209472$$

where $PDIN$ = potential diameter increment (in.)
HIN = height increment (ft.)

The final equation selected for the diameter increment when PHDWD is not specified as an input was:

$$DIN = PDIN\ (b_1\ CR^{b_2}\ e^{-b_3\ CI_p})$$

Table 3. Growth and mortality equations used in the tree and stand growth simulation program PTAEDA2.

Equations used without specifying percent hardwoods	R^2	$S_{y.x}$
$HIN = PHIN(0.26325+2.11119CR^{0.56188} e^{-0.26375\ CI_p - 1.03076CR})$	0.46	0.751
$DIN = PDIN(0.72511188CR^{0.98014576} e^{-0.37397613CI_p})$	0.66	0.085
$PLIVE = 1.02797\ CR^{0.03790} e^{-0.00230\ CI_p^{2.65206}}$	---	-----
Equations used when specifying percent hardwoods		
$HIN = PHIN(0.27861+2.2506CR_{HW}^{0.58852} e^{-0.27575CI_p - 0.24289MCI_{HW} - 1.12339CR})$	0.46	0.751
$DIN = PDIN(0.726022CR_{HW}^{0.9653866} e^{-0.3778245CI_p - 0.1894939MCI_{HW}})$	0.66	0.085
$PLIVE = 1.02788CR_{HW}^{0.03778} e^{-0.00230(CI_p^{2.65114} + MCI_{HW}^{2.65114})}$	---	-----
$MCI_{HW} = MCI_p((1-PHDWD)^{-1.0909} - 1)$	0.94	0.019

Where: PHIN = potential height increment, HIN = actual height increment, PDIN = potential DBH increment, DIN = actual DBH increment, CI_p = pine competition index, MCI_{HW} = mean competition index of hardwoods, MCI_p = mean competition index of pine, CR = crown ratio, CR_{HW} = crown ratio when percent basal area of hardwoods is specified, PLIVE = survival probability, PHDWD = percent basal area of hardwoods, e = base of the natural logarithm.

where DIN = diameter increment (in.)
CR = crown ratio
and all other variables are as previously defined.

When the optional PHDWD is specified, the diameter increment equation used in the model is:

$$DIN = PDIN\ (b_1 + CR_{HW}^{\ b_2}\ e^{(-b_3 CI_p - b_4 MCI_{HW})}$$

where all variables are as previously defined.

The two equations for predicting DIN were fitted to the data using non-linear least squares (Table 3). DIN decreases with increasing competition and increases with increasing crown ratio. A normally distributed random component is added to growth determinations with variance equal to the residual mean square from the fitted regression.

The inclusion of crown ratio as a measure of photosynthetic potential in the above models plays a key role in determining thinning response. When a tree is released by removing neighboring trees its response will depend not only on the reduction in competition for resources, but the potential it has for using those resources. Crown ratio reflects this potential.

Crown ratio is predicted annually as a function of height, DBH, age and, when specified, percent hardwood basal area (Table 2).

<u>Mortality</u>

The probability that a tree remains alive in a given year was assumed to be a function of its competitive stress and individual vigor or photosynthetic potential. An equation describing that probability was developed using non-linear least squares and methodology proposed by Hamilton (1974) for fitting probabilities to dichotomous 0,1 data (Table 3). The probability of survival equation when PHDWD is not specified is:

$$PLIVE = b_1\ CR^{b_2} e^{-b_3 CI_p^{\ b_4}}$$

where PLIVE = probability that a tree remains alive
and all other variables are as previously defined.

When PHDWD is specified the PLIVE equation is:

$$PLIVE = b_1\ CR_{HW}^{\ b_2}\ e^{-b_3 (CI_p^{\ b_4} + MCI_{HW}^{\ b_4})}.$$

PLIVE increases with increasing crown ratio and decreases with increasing competition. When crown ratio is one and competition index is zero, PLIVE takes on its maximum value, b_1. That this 'probability' is greater than one is of no practical concern in predicting PLIVE under stand conditions.

In PTAEDA2, survival probability is calculated for each tree and used in Bernouli trials to stochastically determine annual mortality. The calculated PLIVE is compared to a uniform random variate between zero and one. If PLIVE is less than this generated threshold, the tree is considered to have died.

<u>Varying Hardwood Competition Level</u>

Besides competitive pressures exerted by neighboring pines, tree growth on cutover sites is often affected by competition from neighboring hardwoods. The competition exerted by a hardwood depends on its relative size and proximity to pines as well as certain species specific attributes which are difficult to quantify. Two methods are available in PTAEDA2 for accounting for the effects of hardwood competition on the pines. In the first method, the competition index of each pine is determined by its size and the sizes and proximity of neighboring pines only. This method is the default method in the model and reflects the mean level of hardwoods in the data set (approximately 5 percent of the basal area in the main canopy in hardwood).

The second method assumes that the crown ratio of all pines in the stand will be affected by the level of hardwood competition according to the equation:

$$CR_{HW} = 1 - e^{(-1.43593-38.32743A^{-1})(D/H)(1-PHDWD)}$$

where all variables are as previously defined. This method also asumes that, for a given size and distance to a subject pine, the competition index for a hardwood regardless of species would be the same as for a pine of the same size and distance. Moreover, since hardwoods are not grown in the simulator on an annual basis along with the pines, the effect of the hardwoods is applied as an average to all pines in the stand according to the equation:

$$MCI_{HW} = MCI_{p}((1-PHDWD)^{-1.0909} - 1)$$

where MCI_{HW} = mean competition index of the hardwoods

MCI_{p} = mean competition index of the pines

PHDWD = percent overstory basal area in hardwoods.

Using this second method requires specifying PHDWD as an input to the model either initially or at some point during the rotation. Burkhart and Sprinz (1984) showed that the level of PHDWD remains relatively constant over rotation lengths of usual interest. Therefore, for many purposes, it may be useful to specify a desired level of PHDWD initially and retain this level throughout the rotation. However, the simulator accommodates changing levels of PHDWD which might more accurately reflect specific stand conditions. For example, a thinning and hardwood release regime can be simulated where PHDWD is initially specified at a particular level, say 10 percent, and remains at this level until the age of thinning. Then, at the age of thinning, the stand can be simultaneously thinned and released from hardwood competition (PHDWD set to 0). This capability offers the user the opportunity to evaluate the impact of thinning, hardwood release or hardwood ingrowth on stand development. Levels of PHDWD from 0 to 90 percent can be inputted to the model by the user.

Stock-Table Options

There are three stock-table options in PTAEDA2: (1) cubic-foot, (2) cords-board feet and (3) user-specified coefficients for combined-variable equation forms. At the beginning of each run the user may select an output option. If option 1 is selected a stand and stock table consisting of numbers of trees, average height, basal area, cubic-foot volume (ob) of the total stem for all trees 1-inch dbh and greater, and cubic-foot volume (ob) to a 4-inch top diameter (ob) for all stems in the 5-inch dbh class and above, will be generated by 1-inch dbh classes. A final volume column may be 'customized' according to the user's specifications. First, the user indicates whether cubic-foot volume is to be computed (1) inside bark, or (2) outside bark. Second, a threshold dbh class is specified (i.e., minimum dbh class to be included in stock table and must be entered as an integer, e.g., 4, 5, 6, etc.). Third, the user specifies the top diameter limit (ob) (this can be any real number that is less than the threshold dbh specified). The default condition is cubic-foot volumes with the final volume column consisting of cubic-foot volume (ob) to a 6-inch top diameter (ob) for all stems in the 8-inch dbh class and above.

The second stock-table option gives a stand and stock table consisting of numbers of trees, average height, basal area, cubic-foot volume (ob) of the total stem for all trees 1-inch dbh and greater, standard cords to a 4-inch top diameter (ob) for all trees in the 5-inch dbh class and above, and board-foot volume. Board-foot volumes shown vary according to user specified inputs. First the user chooses a log rule: (1) International 1/4-inch, (2) Doyle, or (3) Scribner. Second, the user specifies the threshold dbh class for board-foot computation; this must be an integer greater than or equal to 8. All board-foot volumes are computed to a 6-inch top diameter limit (ib). Any tree with a D^2H value (D = dbh in inches, H = total height in feet) less than 3800 is assumed not to qualify for sawtimber and its board-foot volume is set equal to zero.

In the third stock-table option, the user can specify a title for the volume or weight units chosen, the threshold dbh for stock table computations, and the intercept (a) and slope (b) value for the combined-variable equation

$$V = a + bD^2H$$

where D = dbh in inches
H = total tree height in feet

for up to three columns of output. This feature allows users to specify any desired volume or weight units and to use equations that are applicable to their particular geographic area and utilization practices.

Additional information about the tree volume equations used in PTAEDA2 can be found in the following section.

Tree Volume Equations

The cubic-foot volume equations used in PTAEDA2 were derived using stem analysis data from 445 dominant, codominant or intermediate crown class trees grown in cutover, site-prepared loblolly pine plantations.[1] Total stem volume is predicted by:

$$V_{tob} = 0.18658 + 0.00250D^2H$$

$$V_{tib} = -0.09653 + 0.00210D^2H$$

where V_{tob} = total stem cubic-foot volume, outside bark, stump to tip
V_{tib} = total stem cubic-foot volume, inside bark, stump to tip

D = dbh in inches
H = total tree height in feet

Merchantable volumes to specified top diameters (ob) are predicted from:

$$V_{ob} = V_{tob}(1-0.54583d^{3.22011}/D^{3.03262})$$

$$V_{ib} = V_{tib}(1-0.60828d^{3.14961}/D^{2.99580})$$

where V_{ob} = merchantable cubic-foot volume (ob) to top diameter limit d(ob)
V_{ib} = merchantable cubic-foot volume (ib) to top diameter limit d(ob)
d = top diameter limit (ob)

and other symbols remain as previously defined.

The board-foot volume equations were derived from sample trees felled in plantations in Piedmont and Coastal Plain Virginia, North Carolina, South Carolina and Coastal Plain Delaware and Maryland. Sample trees had to be greater than or equal to 7.6 inches dbh and have at least one 16-foot log to a 5.6-inch inside bark top limit. After the first 16-foot log, 8-foot increments were used until a 5.6-inch top was reached. International 1/4-inch volumes were computed using appropriate formulas (for additional information on log rules, see Avery and Burkhart, 1983). Doyle volumes were computed using the Doyle formula and inside bark diameter plus one-half bark thickness. If computed Doyle volume was less than log length in feet, volume was set equal to length. Scribner volumes for 16-foot logs

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1 Amateis, R. L. and H. E. Burkhart. Cubic-foot volume equations for loblolly pine trees in cutover, site-prepared plantations. Manuscript in review.

were computed using a table in Belyea (1931). For log lengths other than 16-feet, the ratio length/16 was used to adjust the volume.

The following equations were estimated from the data:[2]

$$V_I = -24.3816 + 0.005816(D^2H)^{1.0835}$$

$$V_D = 3.2492 + 0.00003386(D^2H)^{1.5651}$$

$$V_S = -29.7455 + 0.01888(D^2H)^{0.9521}$$

where V_I = International 1/4-inch board-foot volume to a 6-inch top diameter (ib)
V_D = Doyle board-foot volume to a 6-inch top diameter (ib)
V_S = Scribner board-foot volume to a 6-inch top diameter (ib)

D = dbh in inches (ob)
H = total tree height in feet

Cordwood volumes were computed from the 1-inch dbh class conversion factors presented by Burkhart et al. (1972). These conversion factors range from 84 cubic feet outside bark per standard cord for the 5-inch dbh class to 95 for the 13-inch class and above.

Optional Output

PTAEDA2 offers the user optional output selections for obtaining more detailed simulation results. These options produce output in addition to the tables which are automatically produced at each decision period and at rotation. Optional output is selected when inputting the INITIAL DATA at program initiation and is carried through for the length of the simulation. A brief discussion of the stem map and ASCII data file options is presented here.

Stem Maps. Optional stem maps are available from PTAEDA2 for those desiring to see the spacial arrangement of simulated trees. If this option is selected at program initiation, the stem maps will be shown throughout the rotation each time the stand and stock table is presented. The stem maps show the approximate location of living, dead and thinned trees. Due to grid resolution limitations on printers and consoles, tree locations can only be approximated.

The stem maps may be helpful to those wishing to assess mortality and thinning patterns or those desiring to see the effects of various planting regimes on spacing.

ASCII Data File. An ASCII data file containing the individual tree information at rotation age is available as optional output from PTAEDA2. At rotation age, the user can select from three alternative devices to which the tree list will be routed. The name of a disk file can be specified which will cause PTAEDA2 to write the tree list directly to that

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[2] Burk, T. E. 1984. Unpublished research report.

file. Alternatively, typing: CON will display the tree list on the console or typing: PRT will print the tree list. The user can decide which trees should be included in the file. Any combination of live, dead or thinned trees can be specified or all simulated trees can be included.

The individual tree data in the ASCII data file includes the X and Y location coordinates, dbh, total height, crown length, and a code (designated LMORT) which defines each tree's status at rotation (1=dead, 2=live, 3=thinned). For dead trees, the dbh, total height and crown length variables are tree attributes at time of death. A value of zero for these variables indicates the tree died during the juvenile growth period.

For most uses of PTAEDA2, the ASCII file of individual tree data will not be a desired output option. However, the tree list does provide more detailed data about simulation results and may be helpful to those desiring to perform more extensive analyses.

Fertilization

From past simulation work (Ek and Monserud 1974, Hegyi 1974) and personal communications it was concluded that response to fertilizer treatments could be described by increases in site quality. Therefore, subroutine FERT was developed to calculate a site adjustment factor (SAF) which acts as a multiplier on site index for fertilized stands.

Of course, the true nature of fertilizer response depends on many factors such as the element applied, the application rate, mode of application, time of year of application, physiographic province, soil texture, soil origin, soil fertility, and drainage. Sufficient data were not available to aggregate these effects and others and their interactions into a reliable model of fertilization response. Thus, it was not possible to calibrate SAF values with actual fertilizer treatments. Instead, four parameters were included which specify, respectively, the maximum response in site quality, the length of time (from application) in years to attain this maximum response, the length of maximum response and the total length of time of the response. SAF increases linearly from the age of fertilization until the maximum response is reached at some age. SAF is then maintained at this response level for a time equal to the length of maximum response. From that time, SAF decreases linearly until site quality at some later age is the same as the original site quality prior to fertilization. Linear functions were chosen as initial approximations because of the absence of actual data. When fertilizing at planting time, the length of time to maximum response is assumed to be zero and only the remaining three parameters are specified. It was thought that managers in close contact with fertilized stands would have a knowledge of proper values for these parameters.

It has been suggested that tree form improves as a result of fertilizer treatment. It should be pointed out that, when output options 1 and 2 are used, volume estimates in PTAEDA2 for fertilized stands do not include form change, but are computed using the same volume equations used for untreated stands. Thus, fertilized yield estimates from the model may be conservative.

Thinning

Due to the nature of the competition relationships in a model such as PTAEDA2, response to thinning should follow directly from the decrease in competition due to removal of neighbors. This response is moderated somewhat by a tree's own potential for growth as measured in PTAEDA2 by crown ratio.

A user may thin by rows, from below, or by a combination of these methods. Thinning from below includes two options: thinning to an upper diameter limit or thinning to a specified basal area. Depending on which option is chosen, the proper diameter or basal area limit is then specified. In either case, a lower diameter limit may be specified below which trees will not be removed. If the row thinning option is chosen the i^{th} row to be thinned is specified. Due to the algorithm used for row thinning and to the reduced number of trees being simulated, a row thinning may be prescribed in PTAEDA2 at most one (1) time in any simulation run. When a combination of thinning types is used, the row thinning occurs first and the residual stand is then thinned from below as specified.

Stand and stock tables of trees removed during thinning operations can be obtained as optional output from PTAEDA2. When this option is selected, the simulator will produce a stand and stock table after each thinning which displays the trees removed at that particular thinning. At rotation age, PTAEDA2 produces a cumulative stand and stock table of all trees removed during the rotation. Thus, the amount of wood removed at each thinning can be evaluated as well as the cumulative effect of multiple thinnings. As with fertilization, no attempt was made to account for changes in tree form due to thinning treatments.

TESTING AND VALIDATION PROCEDURES

The approach taken to validate and test PTAEDA2 was two-fold. First, the individual growth and survival components were validated using the tree growth data from the 186 'light' thin and 186 'heavy' thin plots from the sample plots in cutover, site-prepared plantations. Second, overall model performance was evaluated for logical trends and relationships.

Validation Data

Since PTAEDA2 was developed using the tree data from the unthinned control plots, the thinned plot data provided a semi-independent validation data set for testing the model. There were 13,739 loblolly pine trees from the 'light' thin plots and 10,457 trees from the 'heavy' thin plots available for testing PTAEDA2. Because the thinned plots came from the same stands as the unthinned controls and were screened to have similar initial conditions, the range of ages, site indexes and stand densities were essentially the same for the model development (unthinned) and validation (thinned) data.

Testing Growth and Survival Equations

The height increment, diameter increment and survival equations in

PTAEDA2 were used to predict the height growth, diameter growth and survival for the thinned plot trees over the three year remeasurement period. Predicted growth and survival were compared to observed by computing residuals. Table 4 summarizes these residuals for the three equations with and without hardwood competition index as part of the modifier.

It can be seen from the residuals in Table 4 that the height and diameter increment equations in PTAEDA2 that were developed from the unthinned plot trees slightly underpredict the growth on the thinned plot trees for the first three year period after thinning. This underprediction bias is larger for the heavily thinned plots than for the lightly thinned plots. The magnitude of these biases is not large, however, and the residual plots show no significant trends across crown ratio or competition index.

The PLIVE residuals in Table 4 show a slight overprediction bias for the survival equations in PTAEDA2. It is reasonable to expect mortality in unthinned stands to be greater than for similar stands immediately after thinning (given that the removals were 'research' rather than 'operational' thinnings). Again, however, these residuals are not large and should not present problems when applying the unthinned-based PLIVE equations to survival after thinning.

It can be seen from Table 4 that including the mean level of hardwoods on each plot in the growth and survival equations does not have much impact on the predictive ability of the equations. It appears that, for the range of these data, knowing the mean level of hardwoods in a stand does not greatly improve predictions on an individual tree basis.

<u>Growth and Yield Relationships</u>

PTAEDA2 was evaluated with regard to certain growth and yield relationships that have been well established. Three simulation runs using different random number seeds were averaged over a range of site indexes and number of planted loblolly pine at ages through 50 years. Figures 2a-b show mean annual increment (MAI) projections for 600 and 1200 trees per acre planted, respectively, at site indexes 50, 60, 70 and 80. It can be seen that MAI culminates sooner and declines faster on higher quality sites at greater densities. Figures 3a-b show relationships for basal area development on site index 50 and 70 land for planting densities of 400, 800 and 1200 trees per acre. For a given density, high site land achieves greater basal areas faster than low site land and for a specified site index, greater planting densities produce more total basal area at least up to some point. Figures 4a-b show survival trends for various combinations of site index and initial density. Competition induced mortality is greater on higher sites planted at higher densities. Mean crown ratio development follows that of survival with smaller crown ratios for higher site-density combinations (Figures 5a-b).

The growth and yield relationships shown in Figures 2-5 indicate that simulation results from PTAEDA2 predict reasonable trends over typical age, site index and initial density combinations.

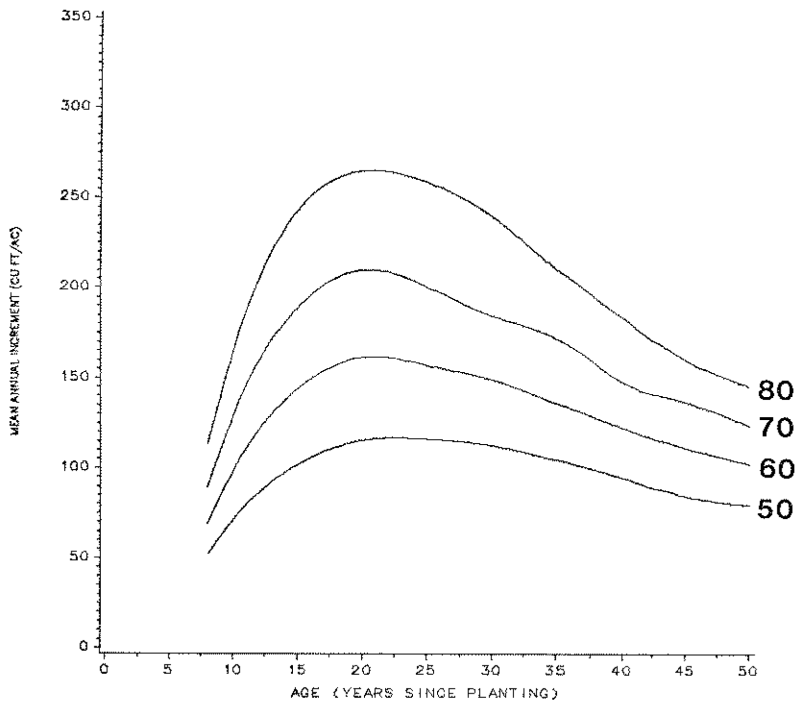

Figure 2a. Projected mean annual increment for 600 trees planted on site index land 50, 60, 70 and 80.

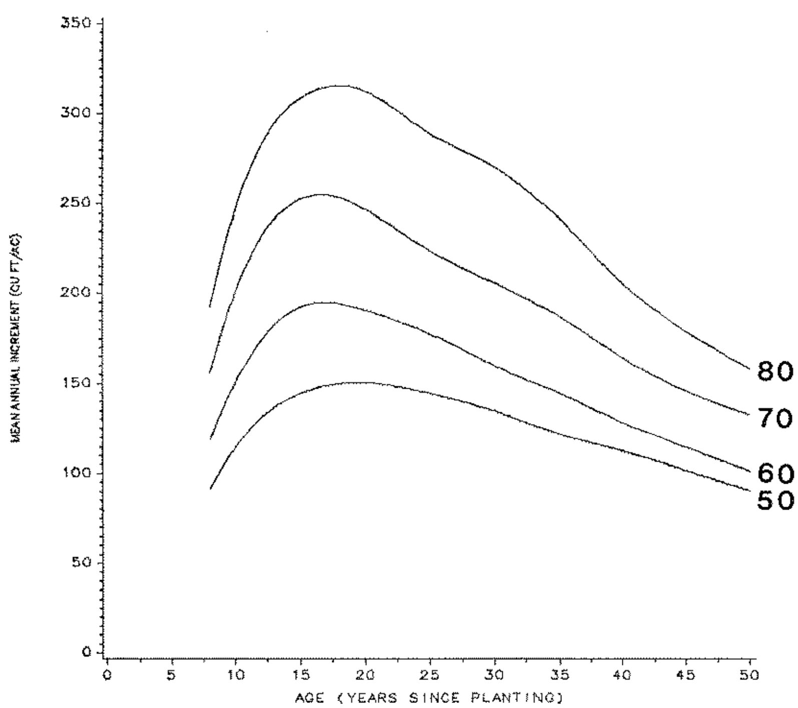

Figure 2b. Projected mean annual increment for 1200 trees planted on site index land 50, 60, 70 and 80.

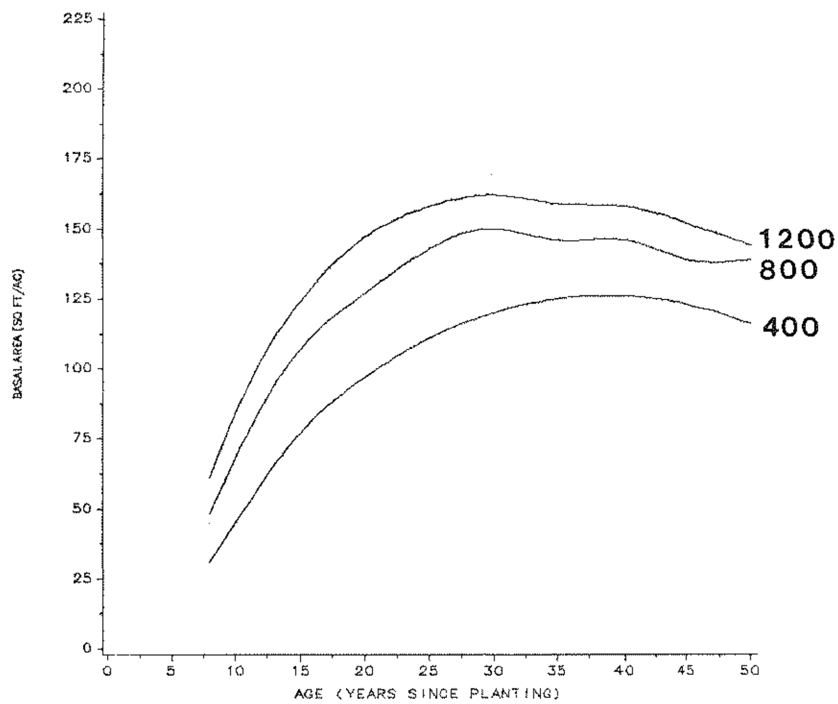

Figure 3a. Basal area projections for site index 50 land and 400, 800, and 1200 trees per acre planted.

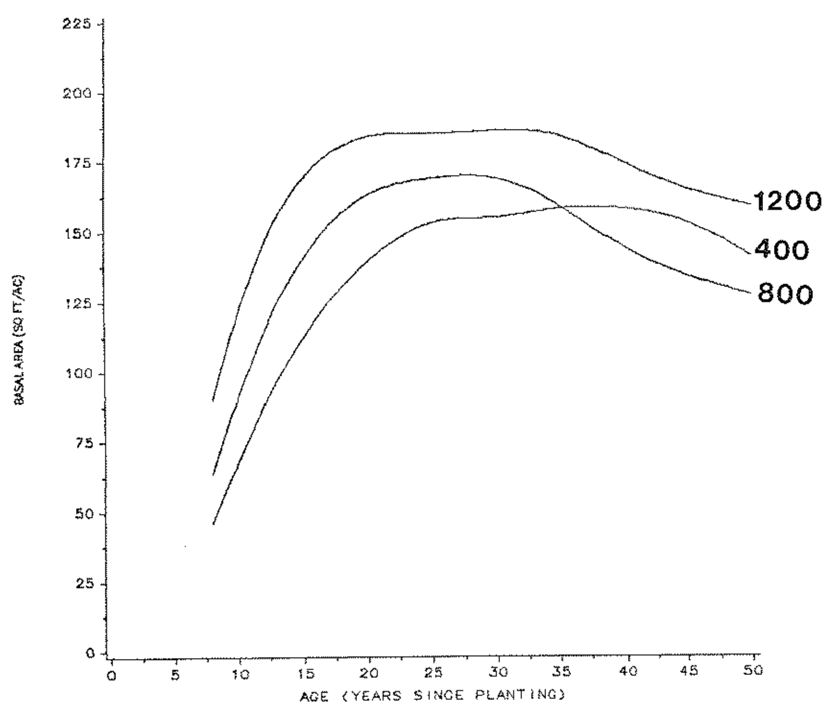

Figure 3b. Basal area projection for site index 70 land and 400, 800, and 1200 trees per acre planted.

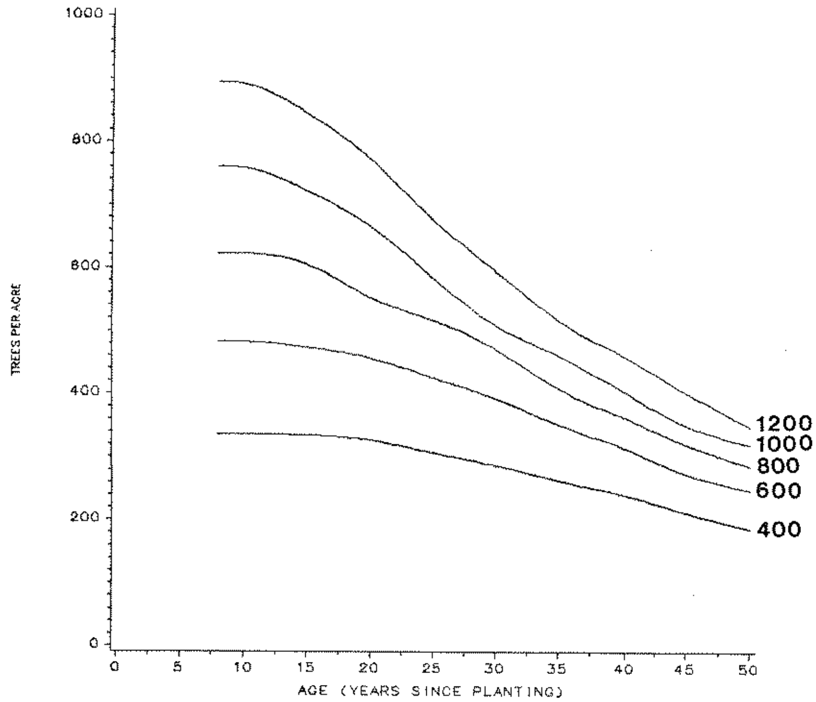

Figure 4a. Projected survival for site index 50 land and 400, 600, 800, 1000, and 1200 trees per acre planted.

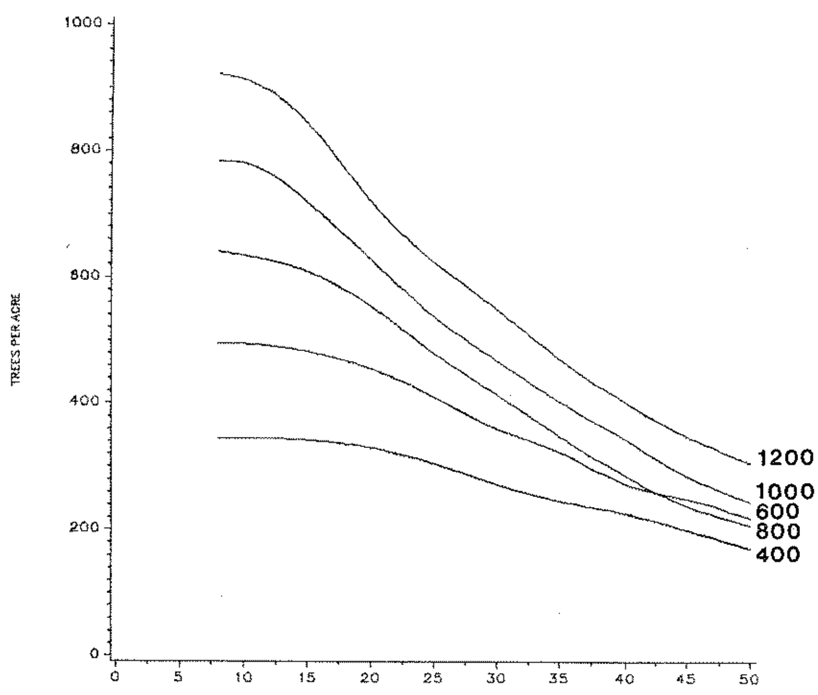

Figure 4b. Projected survival for site index 70 land and 400, 600, 800, 1000, and 1200 trees per acre planted.

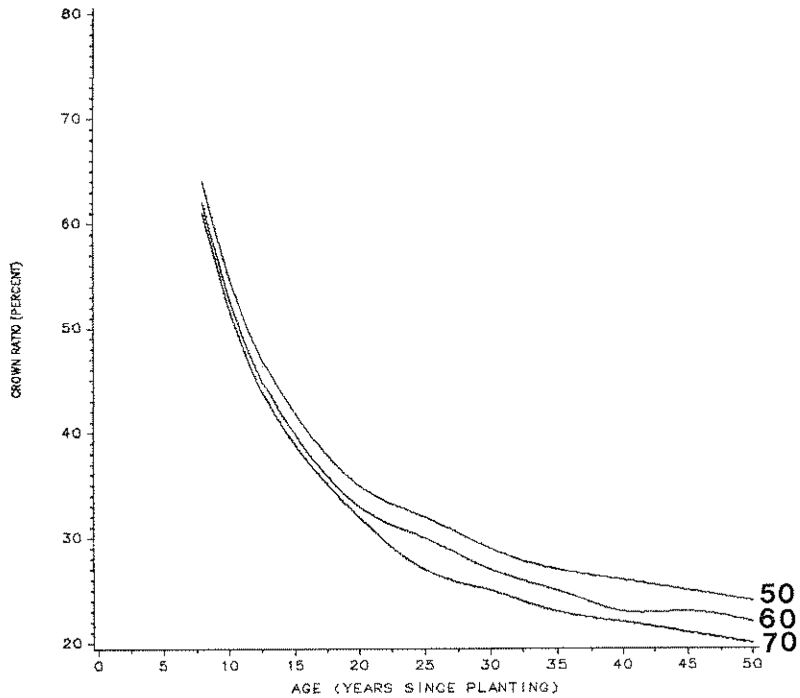

Figure 5a. Projected mean crown ratio for 1200 trees per acre planted and site indexes 50, 60, and 70.

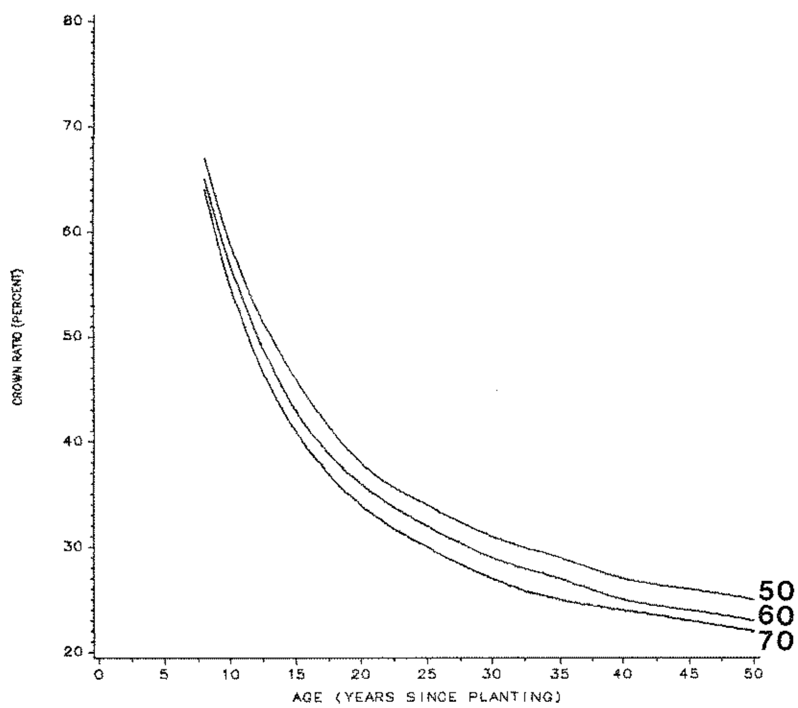

Figure 5b. Projected mean crown ratio for 600 trees per acre planted and site index 50, 60, and 80.

Table 4. Mean residuals (observed minus predicted) and average observed values for the height (HIN) and diameter (DIN) growth equations and the survival equations (PLIVE) found in PTAEDA2.

	Equation[1]					
	Light-Thinned Plot Trees			Heavy-Thinned Plot Trees		
	HIN	DIN	PLIVE	HIN	DIN	PLIVE
Average observed	1.9007	0.2562	0.9943	1.8925	0.2940	0.9941
Mean residual without hardwood component	-0.1728	0.0296	-0.0011	-0.1899	0.0664	-0.0022
Mean residual with hardwood component	-0.1672	0.0365	-0.0010	-0.1838	0.0734	-0.0022

1 Equations are in Table 3.

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PART 2 -- USER'S GUIDE

COMPUTING CONSIDERATIONS

This section discusses computing aspects associated with PTAEDA2 which will be helpful to users of the model.

Hardware and Software

The PTAEDA2 software was written in FORTRAN 77 and consists of approximately 2700 lines of code divided into 30 subroutines and functions arranged alphabetically. The program will execute on any IBM PC/XT/AT or compatible personal computer as well as large mainframes. A minimum of 150K of free memory is required to execute PTAEDA2 on the PC as well as DOS 2.1 or later version. If the source code is purchased, the program can be compiled on the PC using either IBM Personal Computer Professional FORTRAN or MicroSoft FORTRAN. The source code can also be compiled for use on mainframe computers.

The program is designed to accept the INTEL 8087 or 80287 (or equivalent) math coprocessor. Use of this chip increases execution speed considerably and is highly recommended for extensive use of the program.

Batch Mode Operation

PTAEDA2 was written primarily for use in an interactive mode of operation. However, multiple runs can be made in batch mode by developing a DOS batch file (see DOS manual) with the appropriate inputs and requesting stand tables to be printed. This frees the user to leave the terminal while the program is executing.

Execution Speed and Reliability of Predictions

The speed at which PTAEDA2 simulates a particular stand depends on a variety of factors. The most significant of these is the choice of rows and thus the number of trees to be simulated. A run where the number of rows to be simulated is 20 (20 x 20 = 400 trees) takes considerably longer than one where only 5 rows are simulated (5 x 5 = 25 trees). However, there is a tradeoff between execution speed and variance of predictions. The predictions associated with small numbers of trees, such as the 5-row simulation, can be expected to be much less reliable than those associated with the larger number of trees such as the 20-row simulation. This is especially true when trees are removed in thinnings or lost to mortality over longer rotations. As an example, Table 5 displays the variability in basal area associated with an eight-row (64 trees), twelve-row (144 trees) and 18-row (324 trees) simulation using the same initial conditions. Users wishing to obtain information on variability as well as average values may select a smaller simulation plot size and make repeated runs with different

Table 5. Basal area (sq. ft./ac.) for site index 60 at 35 years and 800 trees per acre planted for three simulated plot sizes and selected random number seeds.

Random Number Seed	No. Rows and Trees Per Row, Plot Size (acres) 6 (0.0450)	12 (0.1800)	18 (0.4050)
68767	141	158	157
113355	147	146	153
242622	117	156	155
915394	161	151	161
821131	147	153	161
Mean	142.6	152.8	157.4
Standard Deviation	16.1	4.7	3.6

random number seeds. Those interested only in estimates of average values will probably find it more efficient to select a larger simulation plot size and make only a single run. For many purposes, a 15-row simulation (225 trees) provides a reasonable tradeoff between execution speed and reliability of predictions.

Another factor significantly affecting execution speed is the choice of planting method. A stand planted with exact regular spacing executes significantly faster than either the hand or machine planting options. Selection of either of the latter two options complicates the competition index calculations resulting in an increase in overall simulation time.

Random Number Generation

The random number generator used in PTAEDA2 is from Mihram (1972). While this algorithm does not generate completely independent random numbers, this should pose no practical problems for most users. The effect of altering the random number seed for different plot sizes is shown in Table 5. It is evident that when larger plot sizes are simulated, the choice of random number seed has a negligible effect upon predictions.

EXAMPLE

In this example, the general program flow of PTAEDA2 is discussed along with the interaction between the program and the user. After discussing the main input screens associated with the program, an example is shown.

General Program Structure and User Interaction

User interaction with PTAEDA2 revolves around two main screens: the INITIAL DATA screen and the MANAGEMENT DATA screen. A third screen with the PTAEDA2 logo (Figure 6) is displayed at program initiation and prompts the user to continue or terminate the session. To continue, the user types 'Y' (for all prompts, typing 'Y' and 'N' is equivalent to typing 'YES ' and 'NO', respectively) and the INITIAL DATA screen shown in Figure 7 will be displayed. This screen lists all variables necessary for initiating model execution and shows the default values associated with each variable. After viewing this screen, the user is given an opportunity to make any changes in the initial data. If changes are desired, then a 'Y' response will cause each variable to be displayed one at a time with its corresponding default value and range of possible values. At each variable, the program halts and gives the user the option of making a change or pressing return to skip to the next variable.

Once all changes have been made, the INITIAL DATA screen is redisplayed showing the current initial data. Once again, the user is prompted to make any additional changes. A 'N' response moves program execution to a choice of continuing with the simulation or terminating and exiting the program. If the choice for continuing is made, then simulation begins. The user is informed of the number of trees being simulated as each year's growth computations are being made. The program halts at the

```
---------------------------------------------------------------------------------
:                                                                               :
:     ********  ********  ********  ********  *******   ********  ******       :
:     **    **     **     **    **  **        **    **  **    **        **     :
:     ********     **     ********  ******    **    **  ********   ******      :
:     **           **     **    **  **        **    **  **    **  **           :
:     **           **     **    **  ********  *******   **    **  ********     :
:                                                                               :
:                       COPYRIGHT 1987     VERSION 1.0                          :
:     Licensed to:  HAROLD E. BURKHART                                          :
:                   VPI AND SU FORESTRY                                         :
:                   BLACKSBURG,  VA  24060                                      :
:                                                                               :
:       Simulation of Individual Tree Growth and Stand Development in           :
:         Loblolly Pine Plantations on Cutover, Site-Prepared Areas             :
:                                                                               :
:     By  K. D. Farrar, R. L. Amateis, H. E. Burkhart, and R. F. Daniels        :
:                School of Forestry and Wildlife Resources                      :
:            Virginia Polytechnic Institute and State University                :
:                      Blacksburg, Virginia 24061                               :
:                                                                               :
---------------------------------------------------------------------------------

Do you wish to continue? (YES or NO):
```

Figure 6. PTAEDA2 logo screen.

```
                              INITIAL DATA
Title: PTAEDA2 Simulation Run
No. of simulated growing seasons:  35  Random number seed:       68767
Site Index (base age 25):  60.0        Simulation size: 15 rows by 15 trees

                         PLANTING INFORMATION
                         --Regular Spacing--
Distance (ratio) between rows:  1.0    Distance (ratio) between trees:  1.0
                    Trees planted per acre:  800.0

                      FERTILIZATION INFORMATION
                         --Not Fertilized--

                         HARDWOOD COMPETITION
               --Included as part of original data set--

                          OUTPUT INFORMATION
Juvenile stand output: NO              Thinning report output: NO
Stem map output: NO                    ASCII file output: NO
                      No further input is desired
                       Volume units in cubic feet

Do you want to make any changes? (YES or NO):
```

Figure 7. PTAEDA2 initial data screen.

```
MANAGEMENT DATA - After Growing Season  10

THINNING INFORMATION
--No Thinning Planned--

FERTILIZATION INFORMATION
--No Fertilization Planned--

HARDWOOD COMPETITION
--Included as part of original data set--

INPUT INFORMATION
Next decision is after growing season:  15


Do you want to make any changes? (YES or NO):
```

Figure 8. PTAEDA2 management data screen.

requested age of first management routine. If the requested age is the length of simulation (default), the program produces the requested output information at rotation age. If an intermediate age was specified, the program halts at the end of the growth period for the requested year and the current stand is displayed. After the current stand has been shown to the user, the MANAGEMENT DATA screen is displayed (Figure 8). At this point, the user has an opportunity to request thinning or fertilization, alter the level of competing hardwood basal area, and/or select the next input age. After making changes, the updated MANAGEMENT DATA screen reappears offering another opportunity to make changes. If no more changes are requested, the user again has an opportunity to continue the simulation or terminate and exit the program. If choosing to continue, the program will execute to the next stand summary output age where the same procedure occurs unless the program is at rotation age. At rotation age, final output is displayed and the opportunity to terminate and exit the program or simulate another stand is offered.

Sample Run

Suppose a forest manager wishes to simulate a loblolly pine plantation established on a cutover, site-prepared area that has a site index of 65, was planted by hand at a spacing of seven feet between trees within a row and ten feet between rows. It is surmised that the planting spot variation is at most 20 percent of both the inter-tree and inter-row distance due to stumps and residual slash. It is anticipated that hardwood basal area will comprise approximately 15 percent of the total basal area of the plantation and that thinning will be necessary at age 17 to achieve desired board-foot yields. At time of thinning, all overstory hardwoods will be removed to help release the plantations. Rotation length will be 35 years and output is desired in cords and Doyle board-feet.

The inputs necessary to implement this regime are described in the paragraphs that follow and shown in Figure 9 (pages 34-47). The circled numbers serve to relate the two.

(1) The GENERAL INFORMATION portion of the INITIAL DATA is altered first. To execute this run, the title was changed to: 'PTAEDA2 TEST RUN'; the random number seed and length of simulation remain at the default values. The new value of site index is entered as 65 and the number of simulated rows is left at the default value of 15.

(2) The PLANTING INFORMATION is entered next. The stand does not already exist and has been planted by hand at a distance between rows of 10 feet and between trees of 7 feet. The maximum variance between rows and trees is 20 percent in each case. Since the actual planting spacing has been inputted, the number of trees planted is inputted as Ø (3) allowing PTAEDA2 to compute the number of trees planted per acre from the spacing.

No fertilization information is necessary (4) but the hardwood percent basal area default of 4.8 is changed to 15 percent (5).

The desired output information (6) is entered next. No juvenile stand output is requested but thinning reports are desired (7). No stem maps or ASCII data file are needed but the growing season completed before next input (8) must be changed from the default value of 35 to 17. The cords and board-feet option (9) is desired and Doyle is the specified log rule (10) for trees in the 8-inch class and above (11) (default).

Following these changes, the INITIAL DATA screen is redisplayed (12) and the user has an opportunity to make additional changes (13) and continue or terminate the session (14) .

After choosing to continue, PTAEDA2 advances the stand through age 17 (15) and halts, displaying the current stand table (16). The user chooses to print the table (not shown) (17) , and then the MANAGEMENT DATA screen is displayed (18). After specifying that changes should be made (19), the forest manager inputs the THINNING INFORMATION (20). The manager desires a low thinning (21) at age 17 (22) to a specified basal area limit (23). The minimum tree diameter to thin is 0.0 (24) to a residual basal area of 65 sq. ft. per acre (25). No fertilization is desired (26) the level of hardwood basal area is set to 0, (27) and INPUT INFORMATION is requested (28). The stand age at next decision period will be after rotation age of 35 so 35 is entered (29). After redisplaying the MANAGEMENT DATA screen (30) and offering the opportunity to make additional changes (31) or to terminate the simulation (32), PTAEDA2 displays the thinning report requested in the initial data. The thinning report consists of three stand tables. The first is the before thinning stand table (33), the second is the stand table of thinned trees (34) and finally the residual stand after thinning (35). An opportunity to print each stand table is given after viewing on the screen. The forest manager chooses to print a hard copy of e ch stand table (36) (not shown). After displaying the tables, the stand is advanced through age 35 (37) at which point the rotation age stand table s shown (38). A printout of this stand is desired (39) (not shown) after which the cumulative list of thinned trees is displayed on the screen (40). This stand table is also printed (not shown) (41). Finally, the opportunity to simulate another stand or terminate the session is offered (42).

```
--------------------------------------------------------------------------------
      Please enter new values or press <RETURN> to keep the default value

              (1)
         GENERAL INFORMATION


Title: PTAEDA2 Simulation Run
Enter new value:
PTAEDA2 TEST RUN

Random number seed:          68767
Possible range:            15 to 2147483647
Enter new value:


Length of simulation (growing seasons):           35
Possible range:              9 to          100
Enter new value:


Site index (base age 25):     60.0
Possible range:     20.0 to    100.0
Enter new value:
65

Number of simulated rows:           15
Possible range:              5 to           20
Enter new value:


                 (2)
         PLANTING INFORMATION


Does the stand already exist? (YES or NO): NO
Enter new value:


Is the stand:
    1) Planted with exact regular spacing?  (fastest)
    2) Planted by hand?
    3) Planted by machine?

Type of planting:           1
Possible range:           1 to          3
Enter new value:            2
```

Figure 9. Example PTAEDA2 simulation.

```
Distance (or ratio) between rows:      1.0
Possible range:      1.0 to   100.0
Enter new value:
10

Distance (or ratio) between trees:      1.0
Possible range:      1.0 to   100.0
Enter new value:
7

Maximum variance (percent) between rows:     10.0
Possible range:       .0 to    50.0
Enter new value:
20

Maximum variance (percent) between trees:     10.0
Possible range:       .0 to    50.0
Enter new value:
20

Number of trees planted per acre (or 0.0):   800.0
Possible range:     50.0 to  2000.0
Enter new value:
0
```

(3)

```
        FERTILIZATION INFORMATION


Does fertilization occur at planting?: NO
```

(4)

```
Enter new value:



        HARDWOOD COMPETITION


Do you want to include hardwood competition?: NO
Enter new value:
y

Percent of basal area in hardwoods:      4.8
Possible range:       .0 to    90.0
Enter new value:
15
```

(5)

(6)

```
        OUTPUT INFORMATION


Do you want juvenile stand output? (YES or NO): NO
Enter new value:
```

Figure 9. (continued).

```
Do you want thinning reports output? (YES or NO): NO
Enter new value:
y (7)

Do you want stem maps output? (YES or NO): NO
Enter new value:


Do you want an ASCII data file at end of run: NO
Enter new value:


Growing seasons completed before next decision:    (8)    35
Possible range:            8 to          35
Enter new value:
17


What units should the volume be expressed in:
    1) Cubic feet?
    2) Cords and board feet?
    3) Custom units?

Output volume units:           1
Possible range:            1 to           3
Enter new value:
2 (9)

For customized board foot rule, specify the following:

Log rule: INTERNATIONAL 1/4
(1 = International 1/4; 2 = Doyle; 3 = Scribner)
Enter new value (1, 2, or 3):
2 (10)

Minimum DBH class:           8
Possible range:            8 to          99
Enter new value:       (11)
```

Figure 9. (continued).

```
                                    (12)
                                INITIAL DATA
Title: PTAEDA2 TEST RUN
No. of simulated growing seasons:  35  Random number seed:       68767
Site Index (base age 25):  65.0        Simulation size: 15 rows by 15 trees

                            PLANTING INFORMATION
                             -- Hand  Planted --
Distance (ratio) between rows: 10.0    Distance (ratio) between trees:  7.0
Maximum variance between rows: 20.0%   Maximum variance between trees: 20.0%
                     Trees planted per acre:        .0

                          FERTILIZATION INFORMATION
                            --Not Fertilized--

                            HARDWOOD COMPETITION
                    Percent of total basal area:  15.0

                             OUTPUT INFORMATION
Juvenile stand output: NO              Thinning report output: YES
Stem map output: NO                    ASCII file output: NO
Growing seasons completed before requesting first management routine:  17
                      Volume units in cords and board feet

Do you want to make any changes? (YES or NO):
n  (13)

Do you wish to continue? (YES or NO):
y  (14)
```

Figure 9. (continued).

```
                    Please Wait
                       (15)

Computing Growth for Growing Season    9
          184 Trees Simulated

Computing Growth for Growing Season   10
          184 Trees Simulated

Computing Growth for Growing Season   11
          183 Trees Simulated

Computing Growth for Growing Season   12
          183 Trees Simulated

Computing Growth for Growing Season   13
          182 Trees Simulated

Computing Growth for Growing Season   14
          178 Trees Simulated

Computing Growth for Growing Season   15
          176 Trees Simulated

Computing Growth for Growing Season   16
          172 Trees Simulated

Computing Growth for Growing Season   17
          170 Trees Simulated


Press <RETURN> for output
```

Figure 9. (continued).

PTAEDA2 TEST RUN

(16)

Live Trees

INPUTS		PREDICTED	
Site Index =	65.0	Dominant Height =	50.6
Growing Seasons Completed =	17.0	Average DBH =	6.3
Planted Trees =	622.3	Average Height =	46.9
Percent Hardwood =	15.0	Average Crown Ratio =	33.8

Press <RETURN> for stand table

DBH Class	Number Trees	Average Height	Basal Area	Total Volume o.b.	Volume Cords To 4.in	Volume Doyle bd.ft.
2	8.3	26.9	.2	3.9	.0	.0
3	24.9	35.3	1.4	26.9	.0	.0
4	52.5	41.0	4.7	98.4	.0	.0
5	77.4	44.9	10.7	234.2	1.8	.0
6	80.2	46.7	15.5	348.2	3.2	.0
7	80.2	48.6	20.8	478.5	4.8	.0
8	63.6	51.3	22.9	551.6	5.6	194.9
9	74.7	52.7	31.8	782.5	8.0	1257.7
10	8.3	55.4	4.3	110.8	1.1	214.7
Total	470.2		112.2	2635.1	24.6	1667.2

Acres simulated = .3616
Trees simulated = 170

(17)

Do you want to print the table? (YES or NO):
y

Figure 9. (continued).

```
MANAGEMENT DATA - After Growing Season  17

              THINNING INFORMATION
             --No Thinning Planned--
  (18)
            FERTILIZATION INFORMATION
           --No Fertilization Planned--

              HARDWOOD COMPETITION
        Percent of total basal area:   15.0

                INPUT INFORMATION
      Next decision is after growing season:  19


Do you want to make any changes? (YES or NO):
y
 (19)

------------------------------------------------------------------------------
   Please enter new values or press &lt;RETURN&gt; to keep the default value

           (20)
    THINNING INFORMATION


Should the stand be thinned? (YES or NO): NO
Enter new value:
y

What kind of thinning? (1=ROW, 2=LOW, 3=both):     1
Possible range:    1 to    3
Enter new value:
2  (21)

Growing seasons completed before thinning:    17 (22)
Possible range:   17 to   34
Enter new value:


What type of low thinning? (1=DIAMETER, 2=BA):     1
Possible range:    1 to    2
Enter new value:
2 (23)

Minimum tree diameter (DBH) to thin:      .0 (24)
Possible range:    .0 to  99.0
Enter new value:


Residual basal area desired:   70.0
Possible range:    .0 to 112.2
Enter new value:
65               (25)
```

Figure 9. (continued).

FERTILIZATION INFORMATION

(26)

```
Should the stand be fertilized? (YES or NO): NO
Enter new value:
```

HARDWOOD COMPETITION

```
Should hardwood basal area level be altered?: NO
Enter new value:
y

Percent of basal area in hardwoods:   15.0
Possible range:     .0 to  90.0
Enter new value:
0  (27)
```

INPUT INFORMATION

(28)

```
Next decision made after growing season:    19
Possible range:   18 to   35
Enter new value:
35            (29)
```

```
                MANAGEMENT DATA - After Growing Season  17
                      (30)  THINNING INFORMATION
Type of thinning: LOW                  Growing seasons before thinning:  17
Low thinning type: Basal area limit    Smallest diameter (DBH) to thin:   .0
            Residual basal area limit:  65.0 sq. ft./acre

                        FERTILIZATION INFORMATION
                        --No Fertilization Planned--

                          HARDWOOD COMPETITION
                    Percent of total basal area:      .0

                            INPUT INFORMATION
        --Simulation will run to completion without further input--


Do you want to make any changes? (YES or NO):
n  (31)

Do you wish to continue? (YES or NO):
y            (32)
```

Figure 9. (continued)

Please Wait

Press <RETURN> for output

PTAEDA2 TEST RUN

(33)

Live Trees

INPUTS		PREDICTED	
Site Index =	65.0	Dominant Height =	50.6
Growing Seasons Completed =	17.0	Average DBH =	6.3
Planted Trees =	622.3	Average Height =	46.9
Percent Hardwood =	.0	Average Crown Ratio =	33.8

Press <RETURN> for stand table

DBH Class	Number Trees	Average Height	Basal Area	Total Volume o.b.	Volume Cords To 4.in	Volume Doyle bd.ft.
2	8.3	26.9	.2	3.9	.0	.0
3	24.9	35.3	1.4	26.9	.0	.0
4	52.5	41.0	4.7	98.4	.0	.0
5	77.4	44.9	10.7	234.2	1.8	.0
6	80.2	46.7	15.5	348.2	3.2	.0
7	80.2	48.6	20.8	478.5	4.8	.0
8	63.6	51.3	22.9	551.6	5.6	194.9
9	74.7	52.7	31.8	782.5	8.0	1257.7
10	8.3	55.4	4.3	110.8	1.1	214.7
Total	470.2		112.2	2635.1	24.6	1667.2

Acres simulated = .3616
Trees simulated = 170

Do you want to print the table? (YES or NO):
y

(36)

PTAEDA2 TEST RUN

Thinned Trees

(34)

INPUTS		PREDICTED	
Site Index =	65.0	Dominant Height =	50.6
Growing Seasons Completed =	17.0	Average DBH =	5.2
Planted Trees =	622.3	Average Height =	44.2
Percent Hardwood =	.0	Average Crown Ratio =	30.5

Press <RETURN> for stand table

DBH Class	Number Trees	Average Height	Basal Area	Total Volume o.b.	Volume Cords To 4.in	Volume Doyle bd.ft.
2	8.3	26.9	.2	3.9	.0	.0
3	24.9	35.3	1.4	26.9	.0	.0
4	52.5	41.0	4.7	98.4	.0	.0
5	77.4	44.9	10.7	234.2	1.8	.0
6	80.2	46.7	15.5	348.2	3.2	.0
7	60.8	48.7	15.2	350.8	3.5	.0
Total	304.2		47.6	1062.4	8.5	.0
Thinned Total	304.2		47.6	1062.4	8.5	.0

Acres simulated = .3616
Trees simulated = 60

(36)

Do you want to print the table? (YES or NO):
y

Figure 9. (continued).

PTAEDA2 TEST RUN

Live Trees

(35)

INPUTS		PREDICTED	
Site Index =	65.0	Dominant Height =	50.6
Growing Seasons Completed =	17.0	Average DBH =	8.4
Planted Trees =	622.3	Average Height =	51.8
Percent Hardwood =	.0	Average Crown Ratio =	39.9

Press <RETURN> for stand table

DBH Class	Number Trees	Average Height	Basal Area	Total Volume o.b.	Volume Cords To 4.in	Volume Doyle bd.ft.
7	19.4	48.5	5.6	127.8	1.3	.0
8	63.6	51.3	22.9	551.6	5.6	194.9
9	74.7	52.7	31.8	782.5	8.0	1257.7
10	8.3	55.4	4.3	110.8	1.1	214.7
Total	165.9		64.6	1572.7	16.1	1667.2
Thinned Total	304.2		47.6	1062.4	8.5	.0

Acres simulated = .3616
Trees simulated = 60

Do you want to print the table? (YES or NO):
y (36)

Figure 9. (continued).

37

```
Computing Growth for Growing Season  18
          60 Trees Simulated

Computing Growth for Growing Season  19
          59 Trees Simulated

Computing Growth for Growing Season  20
          58 Trees Simulated

Computing Growth for Growing Season  21
          58 Trees Simulated

Computing Growth for Growing Season  22
          58 Trees Simulated

Computing Growth for Growing Season  23
          57 Trees Simulated

Computing Growth for Growing Season  24
          57 Trees Simulated

Computing Growth for Growing Season  25
          55 Trees Simulated

Computing Growth for Growing Season  26
          53 Trees Simulated

Computing Growth for Growing Season  27
          52 Trees Simulated

Computing Growth for Growing Season  28
          51 Trees Simulated

Computing Growth for Growing Season  29
          48 Trees Simulated

Computing Growth for Growing Season  30
          47 Trees Simulated

Computing Growth for Growing Season  31
          45 Trees Simulated

Computing Growth for Growing Season  32
          44 Trees Simulated

Computing Growth for Growing Season  33
          44 Trees Simulated

Computing Growth for Growing Season  34
          44 Trees Simulated

Computing Growth for Growing Season  35
          43 Trees Simulated


Press <RETURN> for output
```

Figure 9. (continued).

PTAEDA2 TEST RUN (38)

Live Trees

INPUTS		PREDICTED	
Site Index =	65.0	Dominant Height =	77.0
Growing Seasons Completed =	35.0	Average DBH =	11.3
Planted Trees =	622.3	Average Height =	79.9
Percent Hardwood =	.0	Average Crown Ratio =	30.2

Press <RETURN> for stand table

DBH Class	Number Trees	Average Height	Basal Area	Total Volume o.b.	Volume Cords To 4.in	Volume Doyle bd.ft.
9	2.8	73.4	1.3	45.7	.5	96.6
10	16.6	75.4	9.0	314.2	3.3	707.5
11	47.0	78.1	31.5	1134.8	11.8	2868.7
12	41.5	81.8	32.3	1219.2	12.6	3403.3
13	11.1	89.1	9.8	403.5	4.2	1260.1
Total	118.9		83.9	3117.4	32.3	8336.2
Thinned Total	304.2		47.6	1062.4	8.5	.0

Acres simulated = .3616
Trees simulated = 43

(39)
Do you want to print the table? (YES or NO):
y

Figure 9. (continued).

PTAEDA2 TEST RUN

Cumulative Thinned Trees

(40)

INPUTS		PREDICTED	
Site Index =	65.0	Dominant Height =	77.0
Growing Seasons Completed =	35.0	Average DBH =	5.2
Planted Trees =	622.3	Average Height =	44.2
Percent Hardwood =	.0	Average Crown Ratio =	30.5

Press <RETURN> for stand table

DBH Class	Number Trees	Average Height	Basal Area	Total Volume o.b.	Volume Cords To 4.in	Volume Doyle bd.ft.
2	8.3	26.9	.2	3.9	.0	.0
3	24.9	35.3	1.4	26.9	.0	.0
4	52.5	41.0	4.7	98.4	.0	.0
5	77.4	44.9	10.7	234.2	1.8	.0
6	80.2	46.7	15.5	348.2	3.2	.0
7	60.8	48.7	15.2	350.8	3.5	.0
Total	304.2		47.6	1062.4	8.5	.0

Acres simulated = .3616
Trees simulated = 43

Do you want to print the table? (YES or NO):
y (41)

Another stand? (YES or NO): (42)
n
End-of-Program

Figure 9. (continued).