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Multi-product versus single-product timber rotation : comparative by regression and computer simulation

Faik Sadick Al-Ani

To the Graduate Council:

I am submitting herewith a thesis written by Faik Sadick Al-Ani entitled "Multi-product versus single-product timber rotation : comparative by regression and computer simulation." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Forestry.

G. Ray Wells, Major Professor

We have read this thesis and recommend its acceptance:

David M. Ostermeier, John Rennie, K. F. Schell

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Dr. G. Ray Wells, Major Professor

We have read this thesis
and recommend its acceptance:

Accepted for the Council:

Vice Chancellor
Graduate Studies and Research

MULTI-PRODUCT VERSUS SINGLE-PRODUCT TIMBER ROTATION: COMPARATIVE BY REGRESSION AND COMPUTER SIMULATION

A Thesis

Presented for the

Master of Science

Degree

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ABSTRACT

The study was done in cooperation with staff and assigned personnel of the Division of Land and Forest Resources, TVA, utilizing the simulation power of the agency's WRAP program. WRAP is an acronym for Woodland Resource Analysis Program.

The major purposes of the study were:

1. To develop regression models to examine multi-product versus single-product timber rotations through the financial-optimization procedures of WRAP.
2. To develop regression models to determine the relationship among the financial inputs to WRAP and the income stream generated in WRAP output.

The study had four stages: 1) The generation of individual - stand simulated data through WRAP analysis for natural stands of loblolly pine (Pinus taeda L.); 2) Model building - i.e., definitions of independent and dependent variables and the form of the equations; 3) Regression analysis using both forward and backward stepwise procedures; and 4) Sensitivity testing of the regression equations including graphic illustrations to predict optimum rotations and present worths by different variables.

Twelve separate equations were found by regression analysis using both forward and backward stepwise programs of the SAS package.

"Effective interest rate" was the most important independent model variable in predicting either optimum rotation or present worth. Relative prices of sawtimber versus pulpwood were also very important under the assumptions of the study.

The optimum rotation equations provided by this study varied from 18 to 55 years and should allow users to predict in advance the single product versus multi-product rotations which will be in the WRAP output. This knowledge should allow a better assignment of silvicultural treatments by the user. Price breaks among current product prices were also found for different optimum rotations.

PREFACE

The forest lands in my country, Iraq, are owned by the government. The forests are considered as a part of the agricultural sector and occupy about 81333 sq. km or one-fifth of the total land area (16). The government is responsible for developing forestry and is the decision-maker concerning sizeable forest investments. This study has reviewed how some forest decisions are made in the United States - namely the question of multi-product versus single-product timber rotations. The study involved the use of computer system developed by the Tennessee Valley Authority (TVA) which determines optimum rotations as part of a comprehensive management planning for private forests.

Of wider application to the author has been the exposure to the use of economic analysis and computer applications that could hold promise in the planning and the development of the forest lands in Iraq.

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CHAPTER I

INTRODUCTION

Determination of the best age at which forests should be harvested is one of the oldest problems in forestry (18). The theoretical solutions for an optimum rotation were found long before the development of computer technology. With the development of the computer simulation and statistical models it is now possible to study many of the economic variables that determine rotation age simultaneously and gain better insights into their importance.

WRAP Program

Computations of "optimum rotations" in this study were done in cooperation with the Division of Land and Forest Resources of the TVA utilizing programs of the WRAP system. WRAP is an acronym for Woodland Resource Analysis Program, a system first reported in 1969 (19). The system is a multiple-resource model for allocating woodland resource to assist private landowners in managing their woodlands (3, 11, 23). However, only the timber resource values were used in this study. This study also utilized only a small part of the total system--namely a program in the financial analysis section of the system used to determine the optimum rotations of future stands after the harvest or conversion of the present forest stand. Timber values alone were included in the analysis for the purposes of this study, i.e. non-timber values were not allowed to influence optimum rotations.

The concepts and capabilities of WRAP are being continuously expanded to aid resource managers. In newer versions, many decisions regarding timber production are made directly by the resource expert or forester, who often is in a better position to be familiar with the management variables of a particular forest. Forest product prices, for example, are supplied by the resource manager or program user. Yet these price relationships in turn affect the optimum rotation length and directly influence the types of forest products and income generated to some degree. The relationships among stumpage prices and other economic variables that make it economical to hold stands for all products (sawtimber, poles and piling and pulpwood) rather than single product (pulpwood) rotation were of concern in the study.

Knowledge of the break points among these variables should assist program users in deciding on future stand management strategies and in the assignment of corresponding silviculture treatments.

I. OBJECTIVES OF THE STUDY

The objectives of the study were:

1. To develop regression models that examine single versus multi-product timber rotations within the financial-optimization procedures of WRAP.
2. To develop regression models that determine the relationship among the financial inputs to WRAP and the income stream generated in WRAP output.

II. APPLICATION OF RESULTS TO PROGRAM USERS

One feature of the WRAP program is that either intermediate treatments, such as the number of thinnings, or the percent of the final stands harvested that will produce poles, are assigned by the forester as input before the actual financial optimum rotation is known. Regression equations to predict the rotations likely to be optimum in advance should aid the program user, especially when they can be predicted by other input variables.

CHAPTER II

FOREST INVESTMENT THEORY

According to Thompson (21), investments in forestry can be defined as a commitment of capital for a period of time - usually more than a year. In forest production there are three broad categories of capital investment; those for timber, for land, and for equipment (21). This study centered on capital turnover and the optimum rotation of such investments, and followed traditional forest investment theory used in forest economics to determine the "optimum" rotation. Optimum harvest dates were defined by the maximum soil rent approach through discounting an estimated future income stream with an infinite planning horizon. An explanation of general theory, of WRAP optimization procedures, and general study assumptions are also discussed in this chapter.

Optimum Rotations

Thomson (22) reviewed the original development of forest valuation and identified three doctrines in early German forestry: The gross yield doctrine, soil rent doctrine, and the forest rent doctrine.

Meyer et al. (15) recognized at least three types of rotations: (1) the technical rotation, (2) the silvicultural rotation, and (3) economic or financial rotation. The technical rotation was defined as the culmination of mean annual increment from yield tables of even-aged stands and emphasized maximum production of the desired product. Gross yield, sometimes referred to as the natural or biological rotation, gave longer rotations than the technical since the forests were allowed to stand until growth and mortality were equal. In the United States, some forest industries and the United States Forest Service use the technical rotation to maximize yields.

A silvicultural rotation was defined as a rotation in which stands should be grown to maintain maximum vigor of growth and reproduction. Rotation time, for example, might be extended to allow for seed development and natural reproduction (15).

The "best" economic and financial rotation has been controversial since the earliest periods of forestry, and different theories have developed under different economic systems. The forest rent versus soil rent theories have been the main topic of controversy. Forest rent did not recognize the process of discounting or the time value of capital as included in soil rent (4).

Soil Rent

According to Thomson (22), economists Adam Smith and David Ricardo established the principle which formed the basis for the soil rent doctrine. German foresters developed Ricardo's theory of rent by deriving mathematical formulas. Martin Faustmann used a formula to derive a soil expectation value named in traditional terminology as soil rent. Soil rent was used instead of present net worth because the cost of the land resource *per se* was not included in the formulation, although theoretically considered. Current terminology contrasting soil rent and present net worth distinguishes between continuous rotations and a single rotation (see Gregory (10)) in the discounting process.

In 1957, Mason Gaffney (8), in an exhaustive study of financial maturity, concluded that forest rotations in the United States are on the whole, uneconomically long. He also suggested that a general improvement in capital turnover would occur through wider adoption of Faustmann's formula and the removal of institutional obstacles to its application.

In 1972, Gregory (10) stated that ".... maximizing of present net worth is believed to be the most flexible and useful financial guide to public, as it is to private, timber management." Gregory recognized the work of Gaffney above, i.e., that the Faustmann formula is the theoretically correct calculation of the optimum investment period although in many instances present net worth calculations may be similar (10).

Some forest economists have either argued against setting long-term financial rotations or argued for flexible rotations.

In 1965, Fasick (6) for example, stated the following case:

> A wide range of rotation ages will produce nearly the same financial return. Instead of there being 'an optimal rotation age,' forest managers have many years to harvest a stand without unduly affecting the net return. Flexibility in age permits managers to take advantage of good markets, provide for sudden shifts in raw-material needs of a mill, or plan for an even income flow from a forest with an irregular distribution of age classes.

In general, flexible rotation have short planning periods, 10 years or less, starting with the marketability the individual stand. Most of the approaches utilizing the flexible rotation concept use the "internal rate of return" profit criterion. The return itself is then compared with an owner's alternative rate of return to define the financial maturity of the stand (6, 12, 13, 24, 26). Land costs can be included in the returns calculation (14).

Optimization Procedure of WRAP

WRAP calculation procedures are explained in an unpublished TVA report that documents the system. The portion used for this study calculates a "present value" (net of costs and income) of an infinite number of future stands assuming that the present or actual forest stand was immediately harvested and replaced by another natural stand. In this study, the natural stand replacement was loblolly pine (Pinus taeda L.). All analyses refer to this species and the timber growth simulator of WRAP.

Since the WRAP procedure was written to allow intermediate stand thinnings, they too were "optimized" which theoretically calls for the simultaneous solution of differential equations (See (17) and (20)). The actual "optimum" rotations were selected by an optimal gradient method or computer search procedure which tests for improvements in a "value response" function calculated from the determinants given for an individual stand, product yields, prices, site index, etc. The optimum rotations found and/or predicted in this study were determined from simulated runs utilizing this procedure. However, the WRAP procedure answers should give the same rotation as the classical Faustmann formula or soil rent rotations where only timber values were considered.

I. ASSUMPTIONS

Several assumptions were made in the WRAP procedure regarding inflation, price information, product production, and other variables.

Inflation and the Alternative Rate

Flick (7) and Gregerson (9) point out the necessity of including the effects of inflation when predicting investment returns on forest investments. Forest economists in the past have tended to neglect this important factor, and thus have underestimated the returns in comparison with non-deflated alternative investments.

The alternative rate for landowner or individual investor is the rate the investor can obtain on their investments of equal risks (27).

Duerr (5) described two ways of measuring the alternative or guiding rate of return - either through observing alternative opportunities for investing or alternative opportunities for spending - i.e. the rate of time preference for money (5, 21).

Interest Rate

The WRAP procedures assume a nominal interest rate and a nominal inflation rate, thus using a method described by Gregerson (9) to simplify calculations and precluding the need for determining the real rate and inflationary components.

Thus, in this study the interest rate is referred to as an is "effective interest rate." It is a deflated or real interest rate and approximated by the difference between the alternative rate of return of the landowner and the rate of inflation. This "effective interest" or discount rate ranged from 1 percent to 6 percent based on past experience of WRAP users. In no case would the rate of inflation be allowed to be equal or greater than the landowner's alternative rate.

Price Information

Stumpage prices were obtained from a published source - Timber Mart South (April 1978). A complete price range for the Southeastern United States was found for southern pine pulpwood, poles and sawtimber. Table 1 shows the actual prices used in the analysis. It should be

TABLE 1

SOUTHERN PINE STUMPAGE PRICES FOR THE SOUTHEASTERN USA, APRIL - 1978

Product	Units	Dollars		Rotation
		Median Price	Range	Product Type
Poles	(Per M)[1]	186	148-225	Multiple
Pulpwood	(Per Cord)	10	6-16	Single or Multiple
Sawtimber	(Per M)[1]	113	58-145	Multiple

[1]Doyle (log rule) scale.

SOURCE: (Timber Mart South - Vol. 3 and 4, April, 1978).

pointed out that it is the assumption of relative prices that was important in determining the relations between single-product and multi-product timber rotations.

Pole Production

Pole production where technically feasible and located near markets is a financially attractive component of the multi-product timber rotation (2). Table 1 shows that in general, pole stumpage prices equaled or exceeded sawtimber prices. The WRAP procedure allows pole production to be considered by permiting the forester to estimate the percent of the future stand sawtimber volume in thinnings or harvests that can be included as pole production.

Pole production is intuitively related to stand age and varies directly with the site index. Thus, an internal control over this variable is maintained on very short rotations by checking dominant stand height. Dominant stand height must reach a threshold of 50 feet before any pole production is included in the simulation. This threshold height would be reached earlier on high site index that low index sites. The cross-product or interaction of pole percent times the price of poles was used as an independent variable in all analyses to include the possibility that pole production may not be forcing regardless of the actual percent stated as a variable. Pole percent varied in the analysis from 0 to 70 percent of the total stand volume harvested or thinned.

Silviculture and Thinnings

The study attempted to measure two general cases of thinning. First, the general case of no thinning of a natural loblolly pine stand. The second case involved a specific thinning regime. A silvicultural system used to produce and regenerate natural southern pine for pole production was followed. The regime called for two intermediate thinnings followed by a harvest cut. The last thinning prior to the final harvest removed all basal area to 60 sq. ft. The final harvest was made usually from three to five years later when the basal area grew back to a certain stand minimum. This special assumption caused a built in bias due to the regeneration requirement i.e. thinned stands simulated a light "seed tree" cut. Thus, rotations for the thinned stands in this study versus unthinned stand were always longer, while in practice earlier thinnings might be expected to produce shorter rotations than stands without thinning.

Site Index

The site indexes used were on a 50-year basis and ranged from 63 to 110 feet with a median of 85 feet for loblolly pine. The site indexes under the WRAP procedure are usually estimated by the forester for the individual stands. This variable of course is directly tied to the loblolly pine growth simulator affecting the amount of volume produced over time.

It should be pointed out that site index is the only measured field variable in the section of the WRAP procedure used. All other variables are exogenous to the forest including the prices of products and the landowner's alternative rate and the inflation rate.

Cost Assumptions

An important assumption was made to ignore all other costs with the exception of the discount rate, which is an opportunity cost measuring the cost of time. The rational for excluding costs was that most of the management costs are front-end costs and will not affect the optimum rotations computed. However, any costs that varied with output, such as severance taxes, could and would affect the optimum rotation. Therefore, the discounted net worth or soil rents predicted represent maximum revenues only and are often large in total amount.

CHAPTER III

METHODS AND PROCEDURES

The study proceeded through four main stages: (1) the generation of individual - stand simulated data through WRAP analysis, (2) model building - i.e., definition of dependent and independent variables, (3) regression analysis using forward and backward stepwise regression programs of the SAS package, and (4) studying and interpreting the regression equation including graphic illustrations of the more significant variables from actual predictions.

An outline of work steps accomplished:

1. Identification of the range and medians of the economic variables used as input to WRAP. (Defined and previously discussed in Chapter II.)
2. Generation of data from running the financial optimization portion of WRAP for the combinations of economic variables identified in Step 1.
3. Identification of regression models and equation forms.
4. Solution of the regression equations through two stepwise procedures for each model identified.
5. Evaluation of the sensitivity and breaking-points of the optimum rotations, including graphic interrelationships of variables.
6. Develop guidelines for program users and management strategies.

WRAP Analysis

The financial portion of WRAP, which computes future stand discounted revenues and optimum rotations on an infinite planning horizon, was used to generate approximately 150 case runs. Each run utilized the growth simulator for loblolly pine and a "dummy" set of data representing the extensive range of the six variables normally included as input to WRAP. These input variables and their combinations were the "independent" variables of the later regression models. This approach could be considered a sensitivity analysis of this portion of the WRAP system.

All dummy stands were considered one acre in size and the WRAP output produced two variables for each run: (1) discounted present "net" worth and (2) optimum rotation for each particular combination of the six variables. In general, each variable was varied, holding the other variables at their mid-points, until all combinations were exhausted. Combinations also included an unthinned versus the thinned data runs. (The thinning regime used is discussed in Chapter II.)

Dependent Variables Defined

The two WRAP output variables which were considered the dependent variables for the regression modeling were:

1. Discounted Present Worths - (in dollars) - Approximate soil rent values. All production costs were ignored and the dollar values represented a maximum revenue response discounted by "effective" interest rate. All values therefore include "rate" of inflation.

2. Optimum Rotation Length (rounded to nearest year) - included an infinite number of successive rotations and assumed that the natural unthinned stands were regenerated back the same year of harvest.[1]

Definitions of Independent Variables

The independent variables were as follows:

1. The effective interest rate or the alternative rate less the inflation rate or:

   J-I = effective interest rate.

Where

J = alternative rate

I = rate of interest

2. The percent of volume either of harvestable or thinned stand in poles and pilings production.[2]
3. The stumpage of poles and pilings per M bd. Ft.
4. The stumpage of sawtimber per M bd. Ft.
5. The stumpage of pulpwood per cord.
6. The site index (base 50) of loblolly pine.

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[1] In practice, seed trees would need to be left and a delay of up to five years might be encountered. This elapsed time period was included in the thinned data. The effect of early heavy thinnings to shorten the optimum rotation was not tested in this study.

[2] Simulator only considered poles and pilings after dominant stand height of 50 feet or more. Thus, it varied by site index in height growth and yield function of the stand. Hence, an interaction variable was used of pole percent times the price to be more sensitive to this constraint.

Other transformations of these six variables included:

1. The square of all independent variables.
2. The ratio of all prices of pole and piling stumpage divided by sawtimber stumpage (3/4); and pulpwood stumpage divided by sawtimber stumpage (5/4).
3. Variable two times variable three or the percent of poles times the stumpage of poles.

SAS Analysis

Three general models were identified for regression analysis. (Using the independent and dependent variables discussed previously.) These models were:

1. Unthinned model
2. Thinned model
3. Combined model

These models refer to the way the data from the WRAP analysis were generated. The combined grouped thinned and unthinned data together and included a seventh variable -- thin as a discriminant function, i.e. either -1 or +1. All TVA data were transferred to the IBM 360/65 Computer at The University of Tennessee and analysis conducted with the SAS package program (1).

Regression Models

The following independent variables used in the regression model and their codes using FORTRAN symbols are defined below:

a. SI ---------Site Index

b. PPOLE ------% of Poles

c. PULP -------Pulpwood Price

d. SAW --------Sawtimber Price

e. POLE -------Pole Price

f. EIR --------Effective interest rate

g.[1] ORA --------Optimum rotation age

h.[1] PW ---------Present worth (soil rent)

i. THIN -------Discriminant function for thinning combined data equation only. 1 = unthinned, -1 = thinned.

j. PP x PPR ---PPole x Pole

k. PSRAT ------Pulp/Saw ratio

l. SPRAT ------Saw/Pole ratio

m. $PPPP_{43}$ -----(d/c) x $PPole^2$ or Saw/Pulp x $PPole^2$

n. $PPPP_{54}$ -----(e/d) x $PPole^2$ or Pole/Saw x $PPole^2$

o. P_2PP_{43} -----$PPPP_{54}$ x $PPPP_{54}$ or $PPPP_{54}^2$

p. P_2PP_{43} -----$PPPP_{43}$ x $PPPP_{54}$

In the general regression model used consisted of one dependent variable Y, and the six independent variables X_1 --- X_6 stepwise is used with maximum R^2 improvement.

Model Y = X_1 ----- X_6

A. The general model to calculate the PW, ORA, with combined data set with six independent variables was:

PW = SI, PPOLE, Pulp, Saw, POLE, EIR, $PPole^2$, PP x PPR, PSRAT, SPRAT, SI^2, $PULP^2$, SAW^2, $POLE^2$, EIR^2, $PPPP_{43}$, $PPPP_{54}$, P^2PP_{54}, THIN

---

[1]Dependent variables.

ORA = SI, PPole, Pulp, Saw, Pole, EIR, $PPole^2$, PP x PPR, PSRAT, SPRAT, SI^2, $PULP^2$, SAW^2, $POLE^2$, EIR^2, $PPPP_{43}$, $PPPP_{54}$, P^2PP_{43}, P^2PP_{54}, THIN

B. Thinned Model

PW = SI, PPOLE, PULP, SAW, POLE, EIR, $PPOLE^2$, PP x PPR, PSRAT, SPRAT, SI^2, $PULP^2$, SAW^2, $POLE^2$, EIR^2, $PPPP_{43}$, $PPPP_{54}$, P^2PP_{43}, P^2PP_{54}

ORA = SI, PPOLE, PULP, SAW, POLE, EIR, $PPOLE^2$, PP x PPR, PSRAT, SPRAT, SI^2, $PULP^2$, SAW^2, $POLE^2$, EIR^2, $PPPP_{43}$, $PPPP_{54}$, P^2PP_{43}, P^2PP_{54}.

C. Unthinned Model

PW = SI, PPOLE, PULP, SAW, POLE, EIR, $PPOLE^2$, PP x PPR, PSRAT, SPRAT, SI^2, $PULP^2$, SAW^2, $POLE^2$, EIR^2, $PPPP_{43}$, $PPPP_{54}$, P^2PP_{43}, P^2PP_{54}.

ORA = SI, PPOLE, PULP, SAW, POLE, EIR, $PPOLE^2$, PP x PPR, PSRAT, SPRAT, SI^2, $PULP^2$, SAW^2, $POLE^2$, EIR^2, $PPPP_{54}$, P^2PP_{43}, P^2PP_{54}

Stepwise Procedure

The stepwise procedure was deemed useful for a group of independent variables when the objective was to find out which of the variables should be included in a regression model. Also it was found helpful for analysis because it gave the relationships between the independent variables and the dependent response variable (1).

A. Forward - Stepwise

This selection technique finds the one-variable model which produces the highest R^2. For each of the other independent variables, forward stepwise regression calculates F - statistics reflecting the variables contribution to the model were it to be included (1).

B. Backward - Stepwise

This technique begins by calculating for a model including all the independent variables. Then the variables are deleted one by one until all the variables remaining in the model produce significant F - statistics at the vast step. The variable showing the smallest contribution to the model is the first one deleted at each step (1).

CHAPTER IV

RESULTS

Twelve separate equations were generated by regression analysis using both backward and forward stepwise programs of SAS package. For the three regression models, six equations for PW and ORA were predicted, respectively. Eleven of the twelve equations were different, since only for the ORA (combined data set) did both the forward and backward solutions give identical results.

The equation results are presented next with a complete statistical analysis of the "Final" or selected step presented in Appendix I. The equations are presented with rounded numbers to two significant digits to the right of the decimal.

Present Worth Equations

Six variables and their combinations were used in the analysis to select the best combinations predicting PW.

Forward solution:

Combined equation $R^2 = 0.95$

A. $PW = 3411.67 + 24.47\ SI + 9.68\ SAW - 2829.78\ EIR + 0.05\ PPxPPR + 1.55\ pulp^2 + 288.40\ EIR^2 - 241.23\ Thin$

Thinned equation $R^2 = 0.97$

B. $PW = 4223.07 + 25.38\ SI + 11.55\ SAW - 3242.93\ EIR + 0.06\ PP \times PPR + 331.24\ EIR^2$

Unthinned equation $R^2 = 0.97$

C. $PW = 2518.51 + 23.53\ SI + 40.72\ Pulp + 7.88\ SAW - 2415.69\ EIR + 0.04\ PP \times PPR + 245.43\ EIR^2$

Backward solution:

Combined equation $R^2 = 0.95$

D. $PW = 3670.39 + 24.49\ SI + 35.87\ Pulp - 2830.27\ EIR + 0.05\ PP \times PPR + 0.05\ SAW^2 + 288.47\ EIR^2 - 241.23\ Thin$

Thinned equation $R^2 = 0.97$

E. $PW = 1975.65 + 69.96\ SI - 16.61\ PPole + 30.07\ Pulp + 11.64\ SAW - 3241.70\ EIR + 0.15\ PP \times PPR - 0.26\ SI^2 + 331.06\ EIR^2 - 0.00000033\ P^2PP_{43}$

Unthinned equation $R^2 = 0.97$

F. $PW = 1397.71 + 23.53\ SI + 22.95\ SAW - 2415.75\ EIR + 0.04\ PP \times PPR + 4626.10\ PSRAT - 0.05\ SAW^2 + 245.44\ EIR^2$

Optimum Rotation Age Equations

Forward solution:

Combined equation $R^2 = 0.92$

A. $ORA = 51.32 - 7.48\ EIR + 0.00014\ PP \times PPR - 40.80\ PSRAT + 0.60\ EIR^2 - 6.16\ Thin$

Thinned equation $R^2 = 0.98$

B. $ORA = 60.88 + 0.80\ Pulp - 10.96\ EIR + 0.00014\ PP \times PPR - 40.78\ PSRAT - 0.05\ Pulp^2 + 0.92\ EIR^2$

Unthinned equation $R^2 = 0.98$

C. $ORA + 37.84 - 0.16\ Pulp - 4.00071\ EIR - 0.00015\ PP \times PPR - 26.60\ PSRAT + 0.00014\ SI^2 + 0.27\ EIR^2$

Backward solution:

Combined equation

D. ORA = (Same as forward equation)

Thinned equation $R^2 = 0.98$

E. $ORA = 84.21 - 0.42\ SI - 10.98\ EIR + 0.00014\ PP \times PPR$
$-37.21\ PSRAT + 0.0023\ SI^2 - 0.013\ Pulp^2 + 0.93\ EIR^2$

Unthinned equation $R^2 = 0.98$

F. $ORA = 43.11 - 0.079\ SAW - 4.0022\ EIR + 0.00015\ PP \times PPR$
$- 45.045\ PSRAT + 0.00014\ SI^2 + 0.00028\ SAW^2 + 0.27\ EIR^2$

I. PRESENT WORTH

Combined Equations

In the combined equations predicting (PW) both forward and backward solutions included all six original variables plus the thinning discriminant function. However, the percent of poles and the stumpage of poles were included only in a combined form in both equations. The R squares were similar (0.95 vs 0.95) on both the backward and forward solutions.

In the forward solution the interest rate (EIR) entered first and explained 72 percent of the variation in PW as a single variable.

In the backward solution pole prices and its transformations were deleted in the first four steps.

Thinned Equations

In the thinned data set used to predict PW there were major differences in the forward and backward solution equations. The forward solution contained all variables with the exception of pulpwood price. The backward solution did however contain all variables including a complex variable combining three single variables pole and sawtimber stumpage prices and the percent of poles produced.

Again, in the forward solution EIR was the first entered and explained 75 percent of the variation in present worth as a single variable.

Unthinned Equations

All variables were included in both the forward and backward solutions. However, the backward equations included pulpwood prices as a ratio of sawtimber prices and not as a single variable. Again, EIR or the effective interest rate was the first variable entered explaining 75 percent of the variation in PW. Pole prices and pole production percent were among the first five variables eliminated in the backward solution.

II. OPTIMUM ROTATION AGES

Combined Equations

Identical equations were found using the forward and backward solutions. However, the equation(s) did not include site index as a significant variable. One explanation for the omission is perhaps - high multi-collinearily between pole prices and/or production and site index. When SI was forced to enter the equation none of the variables related to pole production remained significant. The effective interest rate (EIR) was the first variable entered into the forward solution explaining less than one-half (47 percent) of the variation in the optimum rotations.

Thinned Equations

The forward solution thinned equation included all variables except SI. The backward solution, however, did include the square of SI as a significant variable and all other variables in some form as well. Effective interest rate (EIR) explained 88 percent of the variation in rotation length (ORA) in this case. The thinned rotations tended to be from three to five years longer than the unthinned equations due to silvicultural constraints discussed earlier. This may account for the higher correlation with the discount rate in a combined form.

Unthinned Equations

Both backward and forward solutions contained all six variables in some form. Effective interest rate was again the first variable entered explaining 90 percent of variation in ORA as a single variable. The ratio of pulpwood to sawtimber prices were the second variable entered.

III. EFFECT OF DETERMINANTS ON PRESENT WORTHS

Six equations were completed that predict inflated present worths of WRAP output. Since no management costs were included the discounted revenue stream appears high even assuming inflated prices. The combined equation has a minus sign for the thinning coefficient, thus the thinning regime assumed in this study added $241.23 per acre over natural unthinned stand present worth.

Figure 1 shows the effect of effective interest rate and site index on the income stream generated and shows the larger impact the effective interest rate had at the lower rate assumed.

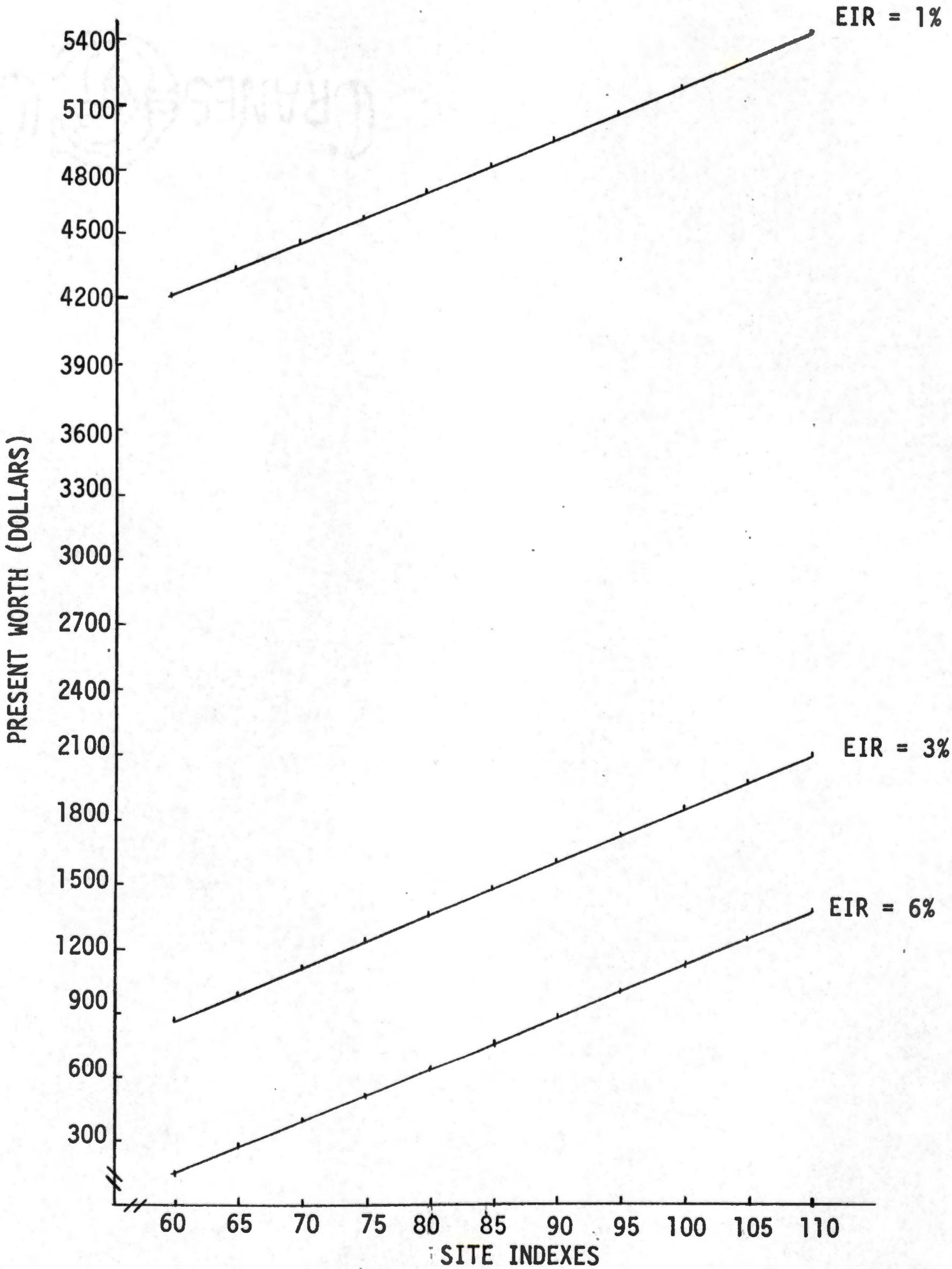

Figure 1. Effect of Effective Interest Rate and Site Index on Present Values - of the Combined Model Assuming Thinning.

IV. THE EFFECT OF SOME DETERMINANTS ON ROTATION LENGTH

Optimum rotation for natural stands of loblolly pine varied in this study from 18 to 55 years under the assumption and range of determinants tested. Thinned stands, low discount rate, low site index, and high sawtimber prices produced the longest rotations; while high interest rate and no pole production in unthinned stands, produced the shortest rotations.

For the unthinned model the relative prices or ratio of pulpwood and sawtimber prices (stumpage) were included and graphed in Figure 2. As expected optimum rotations were somewhat longer with higher sawtimber prices but the largest effect was with pulpwood prices. Here, pulpwood prices had an expected inverse effect on rotation age. If one assumes that the majority of multiple-timber products - i.e., pulpwood, poles and sawtimber occur after 25 years of age, then pulpwood prices can not greatly exceed \$8, \$13, and \$15 at low, median, and high sawtimber prices, respectively, to economically produce these multi-products or the optimum rotations will be short single-product rotations.

Figure 3 shows the same relationship of pulpwood and sawtimber prices for the thinned (forward) model. Even though all rotations were longer than 25 years, a similar relationship of relative prices was found when compared to the unthinned models.

Table 2 shows the relationship of the optimum rotation with all six variables for the unthinned model. When the relationship is positive or direct, higher values of a variable will predict longer rotations usually 10 years long and the converse is true with negative relationships.

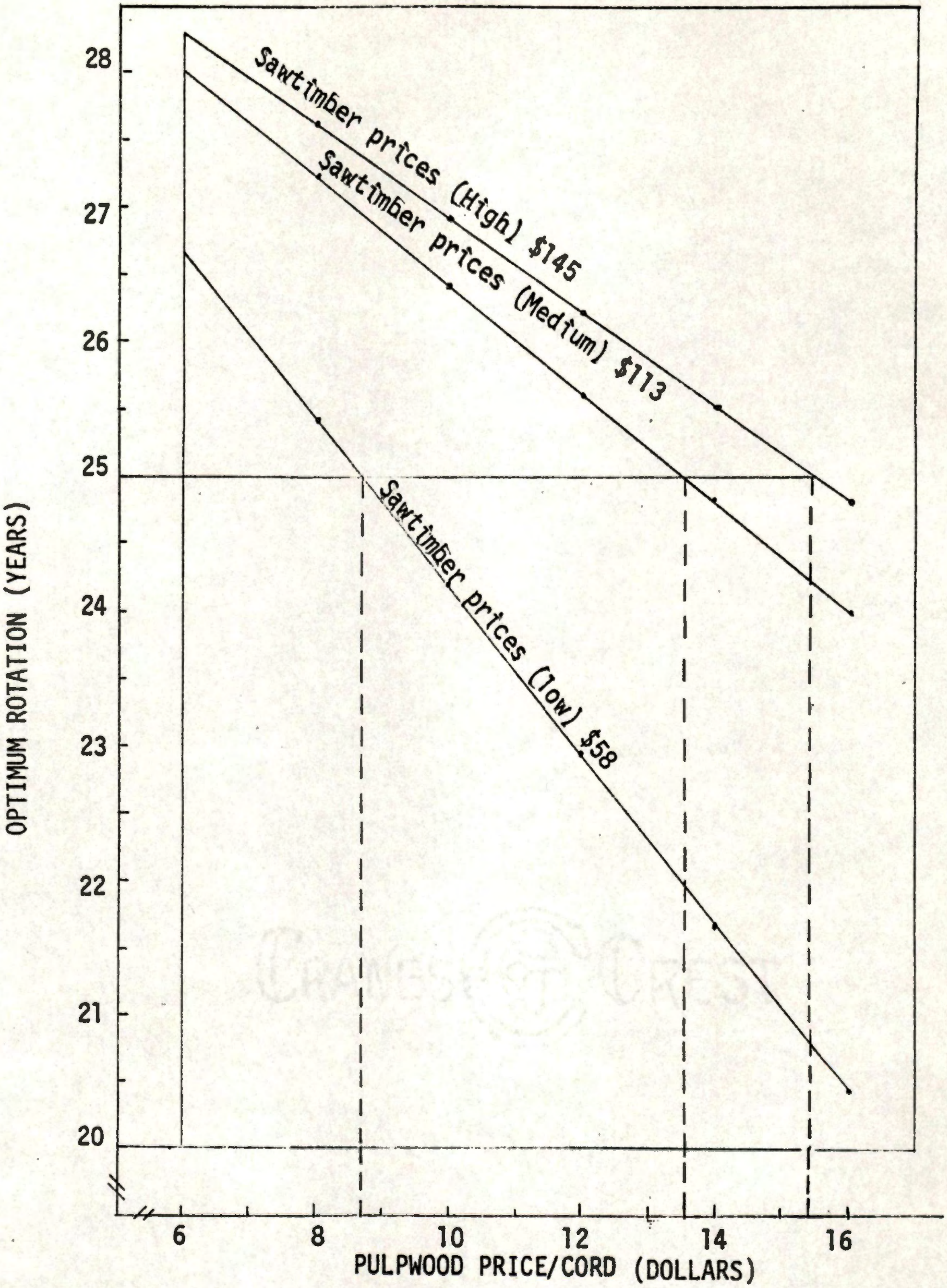

Figure 2. Effect of Relative Prices of Pulpwood and Sawtimber on Rotation Length (Unthinned Model).

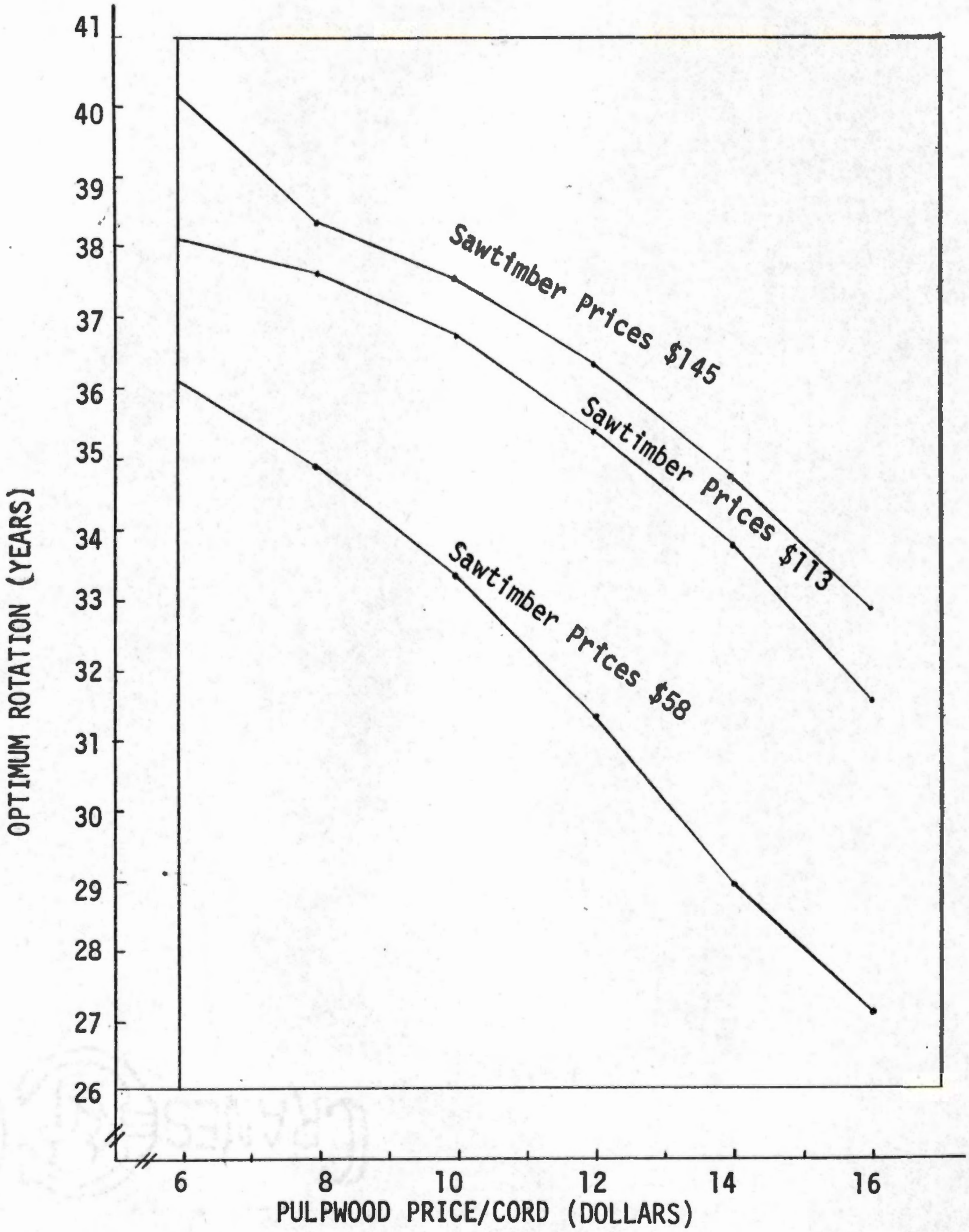

Figure 3. The Effect of Relative Prices of Pulpwood and Sawtimber on Rotation Length Thinned Model - Break Even Prices.

TABLE 2

RELATIONSHIPS OF OPTIMUM ROTATION AND INDEPENDENT VARIABLES

Variable Name	Relationship
Site index	Positive (weak)
Percent of poles	Positive
Price of pulpwood	Negative
Price of sawtimber	Positive
Price of poles	Positive
Effective interest rate	Negative

The only unexpected relationship was the effect of site index and optimum rotation length. This was probably caused by this variables interaction with pole production. Normally high sites should produce short rotations, but in this study high sites allowed pole production to enter into the model earlier and weaken the effect of site index. Thus, pole production masked the effect of normal or expected site index (see Figure 4) and the optimum rotation was changed less than two years, for both thinned and unthinned models, respectively. While in Figure 5, pole production, using the highest site index, only increased the optimum rotation by two years in the unthinned model and one year in the thinned models, respectively.

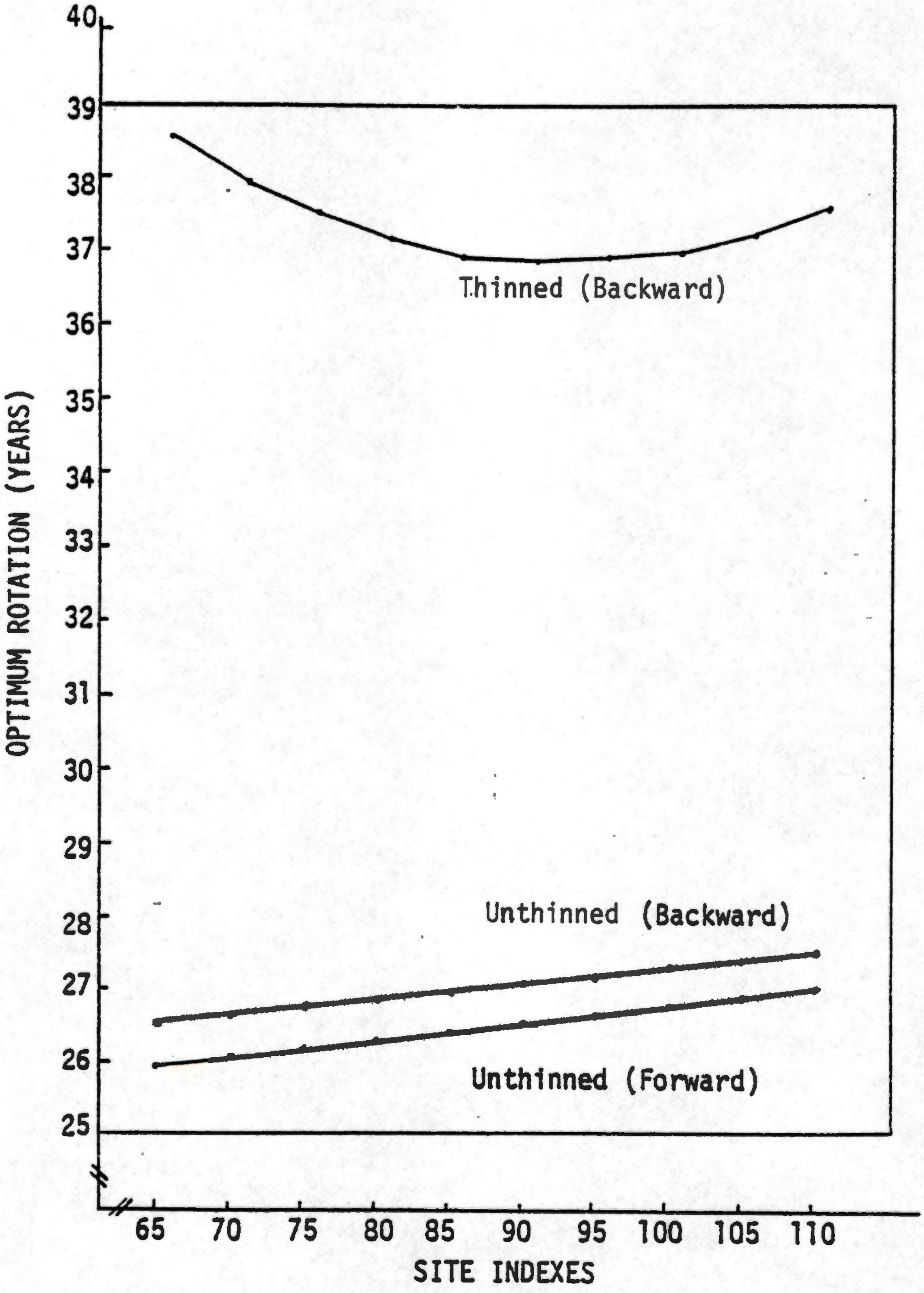

Figure 4. Effect of Site Index on Optimum Rotations.

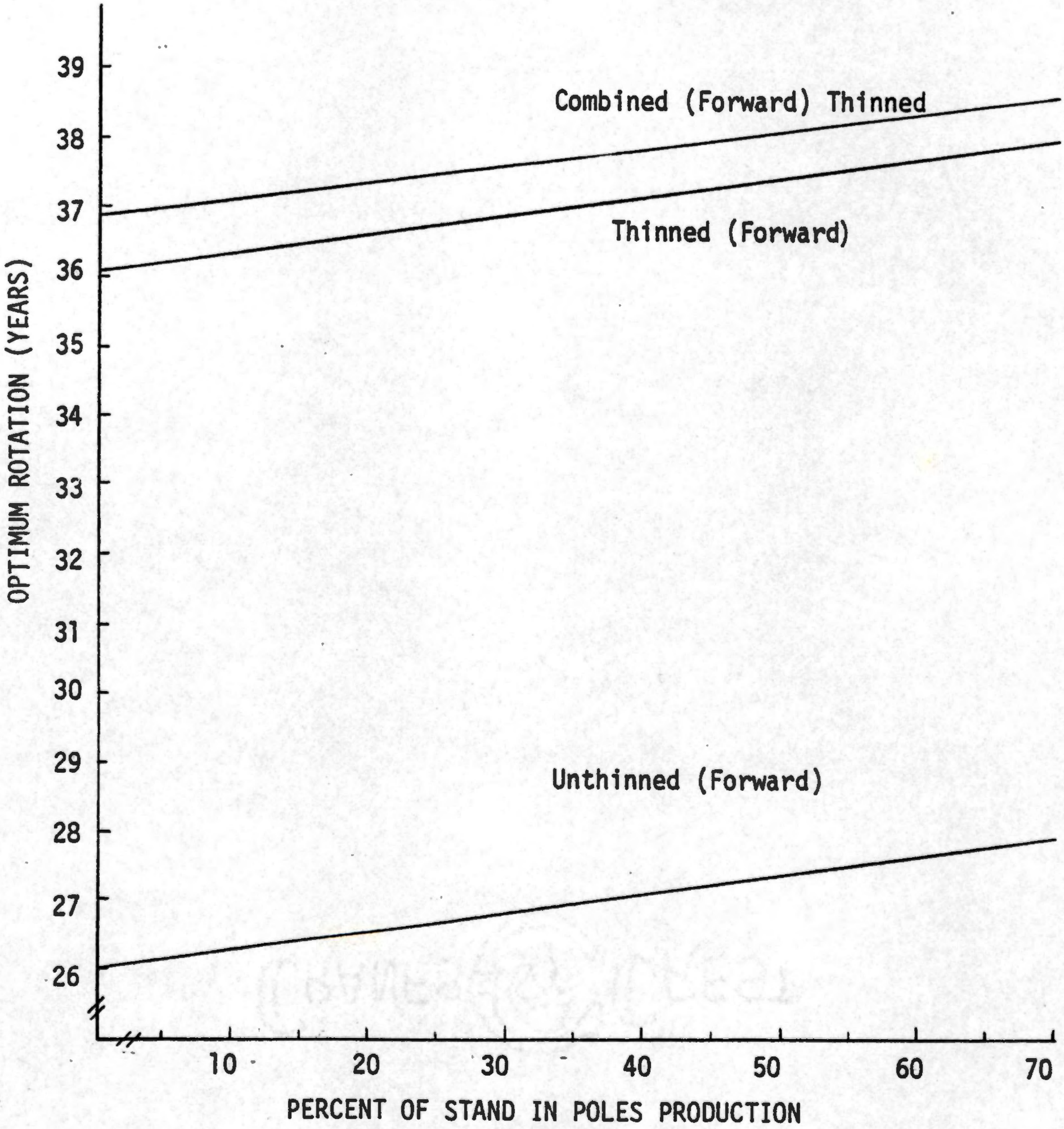

Figure 5. Effect of Pole Production on Rotation Length for High Site Index Values.

The effective interest rate impact on rotation lengths is shown in Figure 6. The single product rotation; assumed 25 years or less, occurred in the unthinned stands at discount rates higher than 3 1/2 percent. All thinned models had rotation greater than 28 years.

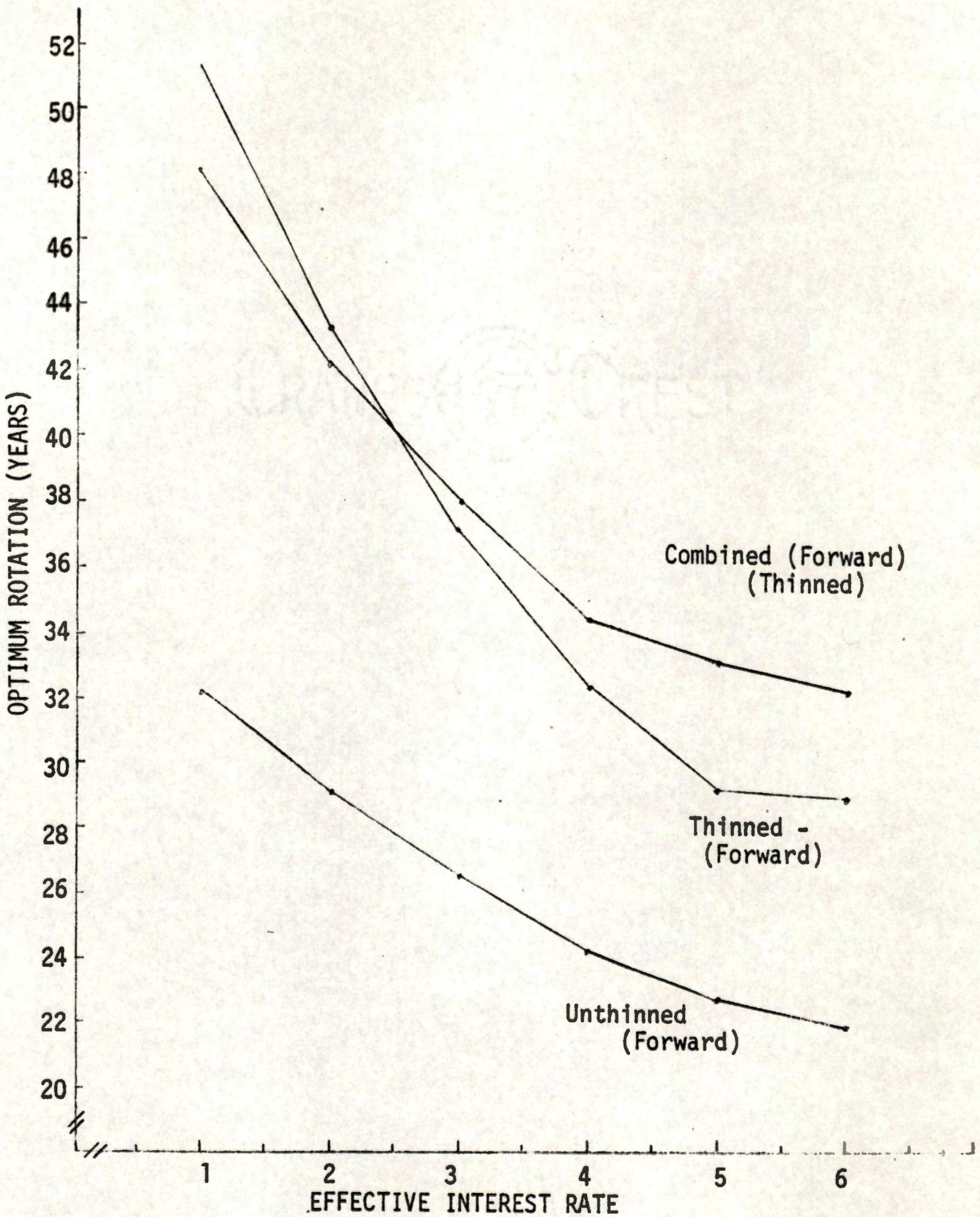

Figure 6. Effect of Effective Interest Rate on Optimum Rotation - Thinned vs. Unthinned Models.

CHAPTER V

MAJOR FINDINGS

The major finding of this study include the eleven separate regression equations that can be used to predict WRAP results. The findings were twofold in purpose. First, the findings aid potential users of the WRAP system. These findings provide and define break-even points regarding specific variable inputs and allow a prediction of the optimum rotation. Thus, silvicultural treatments such as the number of thinnings can be assigned better with this advance knowledge. The second purpose of these equations is to provide a general outlook from the sensitivity tests regarding the current economic rotations for loblolly pine stands under the assumptions of this study.

I. SOME USER GUIDELINES AND BREAK POINTS

1. The effective interest rate is one of the more important variables defining the optimum rotation and present worth. In general, when the effective interest rate is greater than 3 1/2 percent single-product rotations of less than 25 years will occur under the assumptions of the study.

2. Two intermediate thinnings increased discounted revenue $241 above the unthinned stand but resulted in a longer optimum rotation.

3. Relative prices of sawtimber versus pulpwood are important. At sawtimber price of $145, high, $113, median, and $58, low, pulpwood prices must exceed $15, $13, $8, respectively for single product optimum rotation of less than 25 years to occur in unthinned stands.

4. The optimum rotation equations provided by this study, should allow users to predict the optimum rotation length given for loblolly pine for timber values alone. With this advance knowledge users or foresters can make better decisions regarding the number of times, if at all, to thin future stands when filling out WRAP forms.

5. Users should note that site index determination should be done with accuracy and care since it is a particularly sensitive determinant of the discounted present worth in WRAP output. However, it had little impact on optimum rotations.

II. GENERAL FINDINGS

Optimum financial rotation found for loblolly pine in this study varied from 18 to 55 years. This finding is in general agreement with Professor Worrell's hypothesized case for short-rotation management on small properties reported in 1957 especially for unthinned stands without pole production possibilities (25). Exceptions to this rule were outlined in the study including low sites and low discount rates and for thinned stands.

This study was far from a complete economic analysis regarding pole production in loblolly pine. However, some general conclusions were that relative pole prices are currently perhaps just high enough to clear the market with sawtimber prices and perhaps not high enough to justify much longer rotations under present price conditions. However, pole production decisions are more likely marginal, i.e., made by forest landowner later on in the rotation rather than at the time of stand establishment, which also follows the theory of flexible rotations discussed earlier.

III. FUTURE STUDIES

This study raised some interesting questions that should be answered through future study either with the WRAP simulator or with other models.

1. How does WRAP simulation procedure fully react to a range of thinnings? What is the optimum leave basal areas? Would one early heavy thinning shorten the optimum rotation length and by how much? The current study did not really compare unbiasly thinned versus unthinned stands.

2. There is a need to study the economics of pole and piling production. Could marginal analysis starting at later stand age, give different results? How important are individual tree and pole grades (and their probabilities of changing) on the decision to lengthen rotations and allow time for more pole productions?

3. What is the effect of uncertainty on the WRAP output? Could the effect of uncertainty, that is invaribly associated with future happenings be included into WRAP? Accuracy with which optimum rotations can be predicted depends on how accurate future prices (costs) and yields

can be forecast. The statistical output (See Appendix) of the equations of this study might be used to qualify some of the variation of any particular prediction.

4. Studies including costs. For example, how does Forest Incentive Payments (FIP) affect investment decisions? What is the effect of taxation, property and income taxes, on WRAP results?

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TABLE 3

STATISTICS OF THE FINAL SELECTED FORWARD-STEP PREDICTING PRESENT WORTH BY SEVEN INDEPENDENT VARIABLES FOR THE COMBINED MODEL

Step 7	Variable[1] Pulp2 Entered	DF	R Square = 0.95072169 Sum of Squares	Mean Squares	F	Prob F
	Regression	7	629778102.88352460	89968300.41193209	496.10	0.0001
	Error	180	32642989.17365758	181349.93985365		
	Total	187	662421092.05718220			
		8 value	STO Error	Type II SS	F	Prob F
	Intercept	3411.69809616				
	SI	24.47143348	3.69247486	7965281.73707911	43.92	0.0001
	SAW	9.67956278	1.93401637	4542642.99240925	25.05	0.0001
	EIR	-2829.78461632	81.30677202	219669994.78955397	1211.30	0.0001
	PPxPPR	0.05833386	0.00774586	7657645.18356446	42.23	0.0001
	$PULP^2$	1.55365008	0.75203077	774020.77048684	4.27	0.0403
	EIR^2	288.40333805	11.17544236	120778195.08705076	666.00	0.0001
	THIN	-241.21608383	31.05845089	10938817.06720091	60.32	0.0001

[1] All variable names degined on page 16.

TABLE 4

STATISTICS OF FINAL SELECTED FORWARD-STEP PREDICTING PRESENT WORTH BY FIVE INDEPENDENT VARIABLES FOR THINNED MODEL

Step 5	Variable[1] SAW Entered	DF	R Square = 0.96782042 Sum of Squares	Mean Squares	F	Prob F
	Regression	5	402231693.20327144	80446338.64065428	529.33	0.0001
	Error	88	13374018.20651638	151977.47961950		
	Total	93	415605711.40978783			
		B Value	STD Error	Type II SS	F	Prob F
	Intercept	4223.07160766				
	SI	25.38395629	4.78037397	4285229.78605428	28.20	0.0001
	SAW	11.54858923	2.50462523	3231108.96377342	21.26	0.0001
	EIR	-3242.92718059	105.26168947	144249049.10855099	949.15	0.0001
	PPxPPR	0.05985829	0.01002803	5414980.19245441	35.63	0.0001
	EIR^2	331.23638294	14.46798854	79659759.89751334	524.16	0.0001

[1] All variables names defined on page 16.

TABLE 5

STATISTICS OF FINAL SELECTED FORWARD-STEP PREDICTING PRESENT WORTH BY SIX INDEPENDENT VARIABLES FOR UNTHINNED MODEL

Step 6	Variable[1] Pulp Entered	DF	R Square = 0.96960473 Sum of Squares	Mean Squares	F	Prob F
	Regression	6	228709522.48904329	38118253.74817388	462.55	0.0001
	Error	87	7169608.93021226	82409.29804842		
	Total	93	235879131.41925555			
		B Value	STD Error	Type II SS	F	Prob F
	Intercept	2518.51284970				
	SI	23.52629223	3.52014511	3680968.11819074	44.67	0.0001
	PULP	40.71748780	16.46760758	503822.02138348	6.11	0.0154
	SAW	7.88049667	1.84296327	1506780.66015958	18.28	0.0001
	EIR	-2415.68695583	77.51194113	80042435.95427963	971.28	0.0001
	PPxPPR	0.04080677	0.00738438	2516591.68479429	30.54	0.0001
	EIR^2	245.43385083	10.65384602	43735319.76771856	530.71	0.0001

[1]All variables names defined on page 16.

TABLE 6

STATISTICS OF FINAL SELECTED BACKWARD-STEP PREDICTING PRESENT WORTH BY SEVEN INDEPENDENT VARIABLES FOR COMBINED MODEL

R Square = 0.95058479

Variable[1] Erele Removed	DF	Sum of Squares	Mean Square	F	Prob F
Regression	7	629687414.21275180	89955344.88753597	494.66	0.0001
Error	180	32733677.84443034	181853.76580239		
Total	187	662421092.05718220			

	B Value	STD Error	Type II SS	F	Prob F
Intercept	3670.39375981				
SI	24.48714061	3.69758077	7975595.31171734	43.86	0.0001
PULP	35.87105197	17.29757237	782060.25009846	4.30	0.0395
EIR	-2830.27339333	81.41896330	219749522.32917027	1208.39	0.0001
PPxPPR	0.05033662	0.00775661	7658544.89694949	42.11	0.0001
SAW^2	0.04877181	0.00982383	4482274.76228101	24.65	0.0001
EIR^2	288.47316333	11.19085539	120838844.98936065	664.48	0.0001
THIN	-241.22922264	31.10156483	10940008.32846919	60.16	0.0001

[1] All variables names defined on page 16.

TABLE 7

STATISTICS OF FINAL SELECTED BACKWARD-STEP PREDICTING PRESENT WORTH BY NINE INDEPENDENT VARIABLES FOR THINNED MODEL

Variable[1] PPCLE[2] Removed	DF	R Square = 0.96926572 Sum of Squares	Mean Squares	F	Prob F
Regression	9	402832371.01893656	44759152.33543739	294.34	0.0001
Error	84	12773340.39085125	152063.57608156		
Total	93	415605711.40978783			
	B Value	STD Error	TYPE II SS	F	Prob F
Intercept	1975.65494260				
SI	69.95601087	38.69950163	496894.88741733	3.27	0.0742
PPOLE	-16.61380380	19.45546151	110886.90950777	0.73	0.3956
PULP	30.06923962	22.37363147	274661.08461513	1.81	0.1826
SAW	11.64361227	2.50762216	3278509.70359870	21.56	0.0001
EIR	-3241.70470669	105.30051364	144115642.91150010	947.73	0.0001
PPxPPR	0.14845215	0.10337488	313594.30316724	2.06	0.1547
SI2	-0.25569416	0.22034062	204775.34513528	1.35	0.2492
EIR^2	331.06174381	14.47342425	79561069.24617073	523.21	0.0001
$P2PP_{43}$	-0.00000033	0.00000778	280.75548402	0.00	0.9658

[1]All variables names defined on page 16.

TABLE 8

STATISTICS OF FINAL SELECTED BACKWARD-STEP PREDICTING PRESENT WORTH BY SEVEN INDEPENDENT VARIABLES FOR UNTHINNED MODEL

Variable[1] PPOLE Removed	DF	Sum of Squares	Mean Square	F	Prob F
	R Square = 0.96960732				
Regression	1	228710131.99601063	32672875.99943009	391.95	0.0001
Error	86	7168999.42324491	83360.45840982		
Total	93	235879131.41925555			
	B Value	STD Error	TYPE II SS	F	Prob F
Intercept	1397.70545701				
SI	23.52881501	3.54052813	3681494.07249906	44.16	0.0001
SAW	22.94791428	12.13701390	298004.50769465	3.57	0.0620
EIR	-2415.74667253	77.96373682	80034563.49580171	960.10	0.0001
PPxPPR	0.04080603	0.00742687	2516497.79342776	30.19	0.0001
PSRAT	4624.09850670	1880.89931931	504264.90996922	6.05	0.0159
SAW^2	-0.04586882	0.05613013	55667.67900114	0.67	0.4161
EIR^2	245.44238179	10.71600790	43731377.47916289	524.61	0.0001

[1]All variables names defined on page 16.

TABLE 9

STATISTICS OF FINAL SELECTED FORWARD-STEP PREDICTING OPTIMUM ROTATION AGE BY FIVE INDEPENDENT VARIABLES FOR COMBINED MODEL

Variable[1] PPXPPR Entered	R Square = 0.91573952 DF	Sum of Squares	Mean Square	F	Prob F
Regression	5	16292.11666435	3258.42333287	395.59	0.0001
Error	182	1499.09610161	8.23679177		
Total	187	17791.21276596			
	B Value	STD Error	TYPE II SS	F	Prob F
Intercept	51.32236625				
EIR	-7.48220588	0.54796023	1535.74575453	186.45	0.0001
PPxPPR	0.00014124	0.00005220	60.29720711	7.32	0.0075
PSRAT	-40.79914730	7.68681861	232.04221040	28.17	0.0001
EIR^2	0.59745798	0.07531599	518.32054866	62.93	0.0001
THIN	-6.15963323	0.20931489	7132.92330587	865.98	0.0001

[1]All variables names defined on page 16.

TABLE 10

STATISTICS OF FINAL SELECTED FORWARD-STEP PREDICTING OPTIMUM ROTATION AGE BY SIX INDEPENDENT VARIABLES FOR THINNED MODEL

Variable[1] PULP Entered	R Square = 0.97734761 DF	Sum of Squares	Mean Square	F	Prob F
Regression	6	8542.43404125	1423.73900687	625.61	0.0001
Error	87	197.99149067	2.27576426		
Total	93	8740.42553191			

	B Value	STD Error	TYPE II SS	F	Prob F
Intercept	60.88378694				
PULP	0.79682210	0.44744373	7.21727361	3.17	0.0784
EIR	-10.95699054	0.40736023	1646.46537247	723.48	0.0001
PPxPPR	0.00013742	0.00003881	28.53895455	12.54	0.0006
PSRAT	-40.77585717	7.00148883	77.18851237	33.92	0.0001
PULP2	-0.04565401	0.01910827	12.99099891	5.71	0.0190
EIR2	0.92242722	0.05599112	617.66516409	271.41	0.0001

[1]All variables names defined on page 16.

TABLE 11

STATISTICS OF FINAL SELECTED FORWARD-STEP PREDICTING OPTIMUM ROTATION AGE BY SIX INDEPENDENT VARIABLES FOR UNTHINNED MODEL

Variable[1] SI^2 Entered	R Square = 0.98424504 DF	Sum or Squares	Mean Square	F	Prob F
Regression	6	1887.78198977	314.63033163	905.85	0.0001
Error	87	30.21801023	0.34733345		
Total	93	1918.00000000			
	B Value	**STD Error**	**TYPE II SS**	**F**	**Prob F**
Intercept	37.83909331				
PULP	-0.16286656	0.04130792	5.39937925	15.55	0.0002
EIR	-4.00070801	0.15913293	219.53318763	632.05	0.0001
PPxPPR	0.00014505	0.00001516	31.79884607	91.55	0.0001
PSRAT	-26.59581000	2.72765971	33.02118669	95.07	0.0001
SI^2	0.00014400	0.00004115	4.25423271	12.25	0.0007
EIR^2	0.27152972	0.02187250	53.52844061	154.11	0.0001

[1] All variables names defined on page 16.

TABLE 12

STATISTICS OF FINAL SELECTED BACKWARD-STEP PREDICTING OPTIMUM ROTATION AGE BY FIVE INDEPENDENT VARIABLES FOR COMBINED MODEL

Variable[1]		R Square = 0.91573952			
PULP2 Entered	DF	Sum or Squares	Mean Square	F	Prob F
Regression	5	16292.11666433	3258.42333287	395.59	0.0001
Error	182	1499.09610162	8.23679177		
Total	187	17791.21276596			
	B Value	STD Error	TYPE II SS	F	Prob F
Intercept	51.32236626				
EIR	-7.48220588	0.54796023	1535.74575453	186.45	0.0001
PPxPPR	0.00014124	0.00005220	60.29720711	7.32	0.0075
PSRAT	-40.79914740	7.68681871	232.04220577	28.17	0.0001
EIR2	0.59745798	0.07531599	518.32054866	62.93	0.0001
THIN	-6.15963323	0.20931489	7132.92330587	865.98	0.0001

[1] All variables names defined on page 16.

TABLE 13

STATISTICS OF FINAL SELECTED BACKWARD-STEP PREDICTING OPTIMUM ROTATION AGE BY SEVEN INDEPENDENT VARIABLES FOR THINNED MODEL

Variable[1] PULP Removed — R Square = 0.97876072

Variable[1] PULP Removed	DF	Sum of Squares	Mean Square	F	Prob F
Regression	7	8554.78514911	1222.11216416	566.16	0.0001
Error	86	185.64038281	2.15860910		
Total	93	8740.42553191			

	B Value	STD Error	TYPE II SS	F	Prob F
Intercept	84.20892667				
SI	-0.42009091	0.14564839	17.95763828	8.32	0.0050
EIR	-10.97774413	0.39673558	1652.71479111	765.64	0.0001
PPXPPR	0.00013741	0.00003779	28.53715542	13.22	0.0005
PSRAT	-37.21173150	6.68092985	66.96686044	31.02	0.0001
SI^2	0.00228479	0.00082924	16.38720833	7.59	0.0072
$PULP^2$	-0.01250199	0.00439800	17.44305476	8.08	0.0056
EIR^2	0.92539202	0.05453077	621.64464874	287.98	0.0001

[1] All variables name defined on page 16.

TABLE 14

STATISTICS OF FINAL SELECTED BACKWARD-STEP PREDICTING OPTIMUM ROTATION AGE BY SEVEN INDEPENDENT VARIABLES FOR UNTHINNED MODEL

R Square = 0.98436542

Variable[1] POLE Removed	DF	Sum of Squares	Mean Square	F	Prob F
Regression	7	1888.01287341	269.71612477	773.52	0.0001
Error	86	29.98712659	0.34868752		
Total	93	1918.00000000			

	B Value	STD Error	TYPE II SS	F	Prob F
Intercept	43.11253906				
SAW	-0.07898436	0.02482766	3.52896157	10.12	0.0020
EIR	-4.00222921	0.15945271	219.67292570	630.00	0.0001
PPXPPR	0.00014507	0.00001519	31.80633440	91.22	0.0001
PSRAT	-45.04475356	3.84685708	47.80933790	137.11	0.0001
SI^2	0.00014478	0.00004124	4.29789391	12.33	0.0007
SAW^2	0.00028470	0.00011483	2.14349548	6.15	0.0151
EIR^2	0.27174703	0.02191656	53.60697499	153.74	0.0001

[1] All variables names defined on page 16.

VITA

Faik Sadick Al-Ani was born on November 8, 1942, in Ana, Iraq. He attended elementary and secondary schools in that city until he was graduated from Ana High School in 1959.

In the fall of 1959, he entered the High Forest Institute, University of Baghdad, Baghdad, and received a Diploma in Forestry in September 1961 which equaled three academic years.

In November 15, 1961, he entered the Army until April 1, 1964. From November, 1964-1976, he worked for the Ministry of Agriculture and Agrarian Reform. During this time, he also attended the College of Administration and Economics, in Al-Mustansiriyah University, Baghdad, and he was awarded the B. S. degree in Economics in June 1975. In September, 1975, the government sent him for six months training in Agricultural Cooperative in Hungary.

In 1976, he was appointed as an Assistant Director of Al-Es'haki Agricultural Directorate.

In 1976, he received a full scholarship from his government to study for his Master's degree in Forest Economics.

In the summer of 1977, he enrolled in the graduate school at The University of Tennessee, Knoxville, to study for his degree.

He was vice-president of the Organization of Arab Students in The University of Tennessee, Knoxville, during the year 1977-1978.

He is married to Mona Khadom Jaffar. He has three sons, Ahmed, Walleed and Aous.