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STAND STRUCTURE AND YIELD

OF

SLASH PINE PLANTATIONS

ON NON-OLD-FIELDS IN EAST TEXAS

by

J. David Lenhart

REPORT NUMBER 12

TO

PARTICIPATING COMPANIES

IN THE

EAST TEXAS PINE PLANTATION RESEARCH PROJECT

A STUDY OF

LOBLOLLY AND SLASH PINE PLANTATIONS

IN

EAST TEXAS

CENTER FOR APPLIED STUDIES
SCHOOL OF FORESTRY
STEPHEN F. AUSTIN STATE UNIVERSITY
NACOGDOCHES, TEXAS 75962

November, 1986

This is the twelfth in a continuing series of reports describing results from the East Texas Pine Plantation Research Project.

Subject and content of each ETPPRP report is regional in scope and of particular interest to loblolly and slash pine plantation owners in East Texas.

Any suggestions, ideas or comments will always be welcomed.

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This report is based on work by J. David Lenhart.

J. David Lenhart
Project Director
November 21, 1986

STAND STRUCTURE AND YIELD
OF
SLASH PINE PLANTATIONS
ON NON-OLD-FIELDS IN EAST TEXAS

by

J. David Lenhart
Professor, School of Forestry, SFASU

ABSTRACT. A diameter distribution yield prediction system is presented
for slash pine (*Pinus elliottii* Engelm.) plantations on non-old-fields in
East Texas. The system was developed using data from the initial
measurement of the ETPPRP permanent plots in slash pine plantations.

Many of the slash pine plantations in East Texas that were established on sites converted from mixed pine-hardwood stands are approaching possible timber harvest. In order to optimize the timing of the harvests, information is needed on the amount of wood per acre expected at various plantation ages with differing trees per acre and site index values. If, in addition, the wood per acre can be predicted on a dbh class basis, it would assist the forest manager in assigning different stumpage prices to various tree size classes.

With the completion of the initial cycle of measuring the permanent plots of the East Texas Pine Plantation Research Project, a complete data set was available for diameter distribution yield prediction analysis.

In this report, a method is presented to predict the stand structure-number of trees per acre by dbh classes and individual total tree heights by dbh classes-and subsequently, the amount of wood per acre by dbh classes for slash pine plantations on non-old-fields in East Texas.

The material in this report was described in a paper presented at the Fourth Biennial Southern Silvicultural Research Conference in Atlanta, Georgia on November 6, 1986.

PERMANENT PLOT MEASUREMENTS

The ETPPRP permanent plots were installed and measured during the summers of 1982, 1983 and 1984 by a field crew from the School of Forestry at Stephen F. Austin State University.

Each plot consists of two subplots - one to remain unthinned and the other may eventually receive thinning treatments (Lenhart et al. 1985). For our stand structure and yield analysis, the to-remain-unthinned subplot was classified as the regression subplot, and the other subplot was classified as the evaluation subplot. The diameter distribution yield prediction system was developed using the regression subplots and tested using the evaluation subplots.

Within a subplot in a plot, each planted pine was measured as to dbh - nearest tenth of inch and total tree height - nearest foot, among other values.

The observed values available for stand structure analysis were:

1. Age - number of growing seasons completed (A).
2. Stand height - average height of the ten tallest trees (H).
3. Total number of trees per acre (T).
4. Number of trees per acre by dbh class.
5. Minimum dbh - (DMIN).
6. Arithmetic mean dbh - (DMEAN).
7. Quadratic mean dbh - (DQMEAN).

A site index (base age = 25 years) value (S) was predicted for each plot using an equation developed by Blackard (1985a, 1986) and Lenhart et al. (1986).

An exploratory investigation of fitting the Weibull distribution to the observed number of trees per acre by diameter class indicated that a regression subplot had to have trees in three dbh classes or more. If two dbh classes or less were occupied, the fitting routines would usually fail to find a solution.

Thus, the number of slash plots available for analysis was reduced from 78 to 43. Number of plots by county is shown in Figure 1. Distributions of the 43 plots by age, site index and number of trees per acre are illustrated in Figures 2-4.

For the 43 plots, average stand parameters are:
1. Age = 8 years.
2. Height = 27 feet.
3. Site index = 67 feet.
4. Number of trees per acre = 360.
5. Average minimum diameter = 1.1 inches.
6. Average arithmetic mean diameter = 3.6 inches.
7. Average quadratic mean diameter = 3.7 inches.

This is a set of young plots on medium productive sites with very wide tree spacing.

n = 43 plots

FIG. 2 DISTRIBUTION OF SLASH PINE ETPPRP PLOTS
UTILIZED IN REGRESSION ANALYSES BY COUNTY.
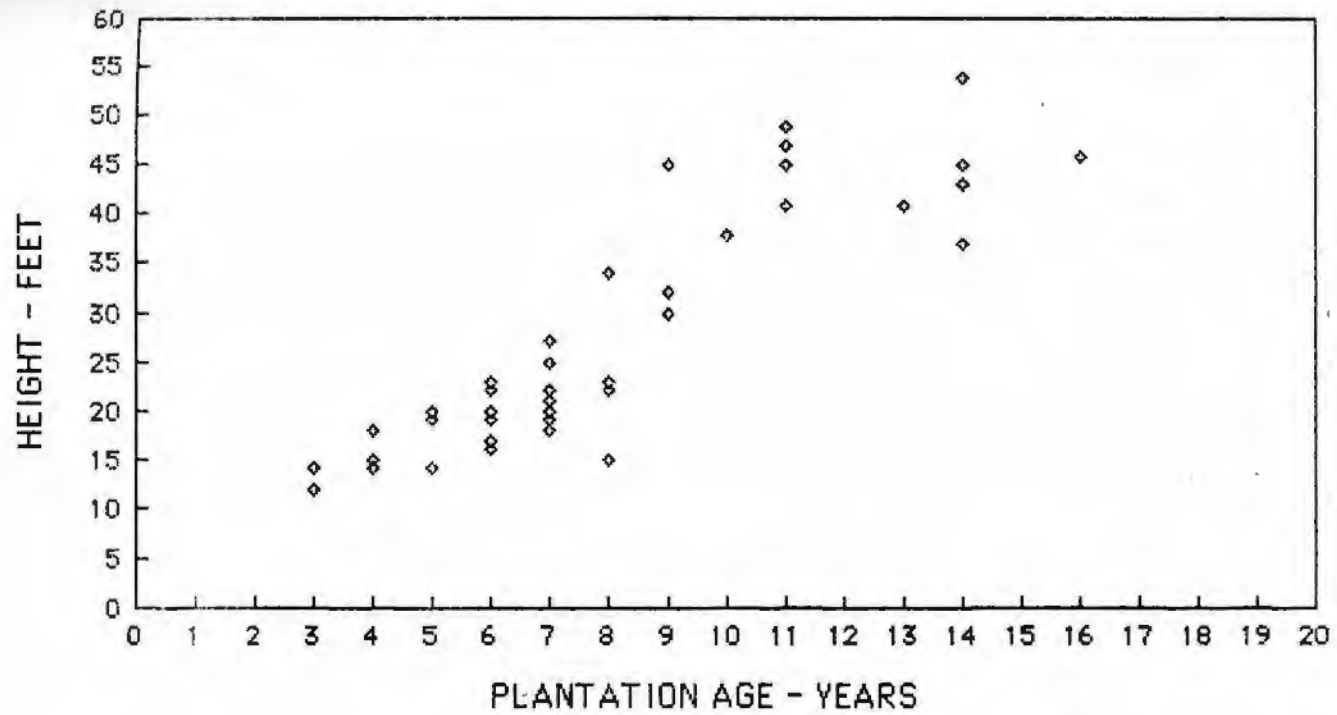
FIG. 2. NUMBER OF SLASH REGRESSION SUBPLOTS
BY HEIGHT AND AGE.   n = 43 obs.
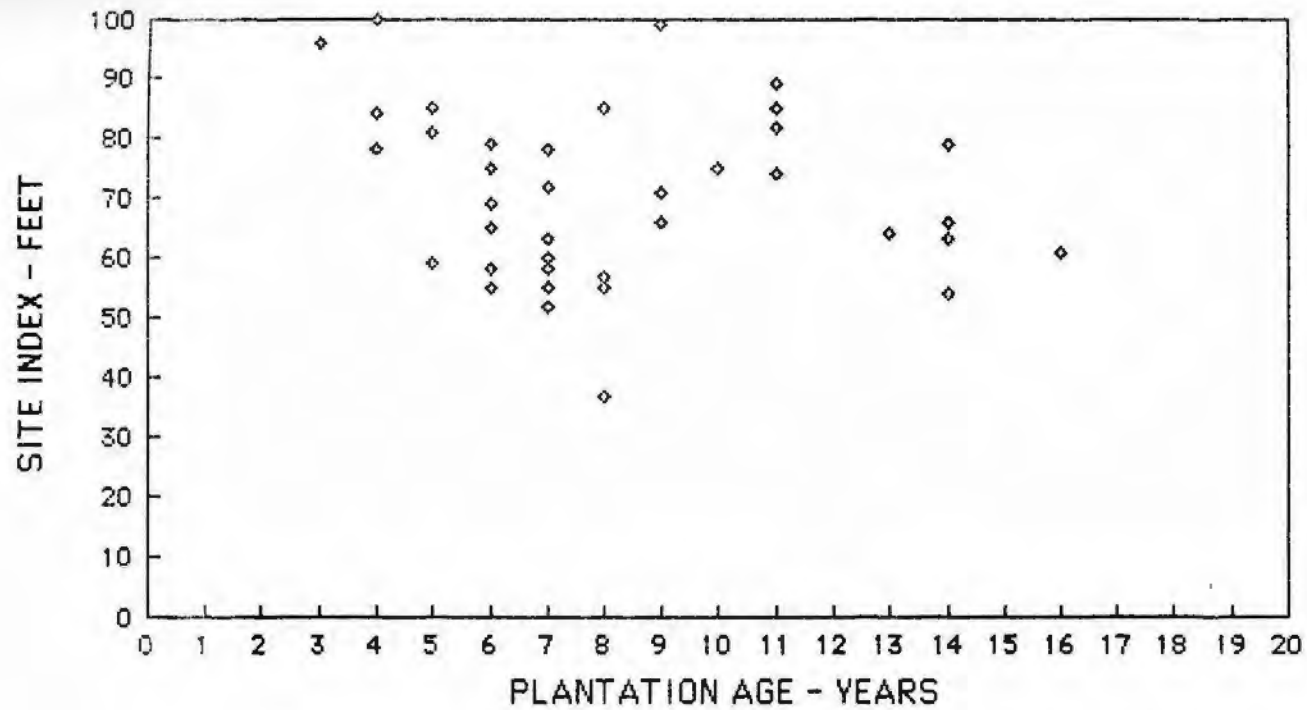
FIG. 3. NUMBER OF SLASH REGRESSION SUBPLOTS
BY SITE INDEX AND AGE.   n = 43 obs.
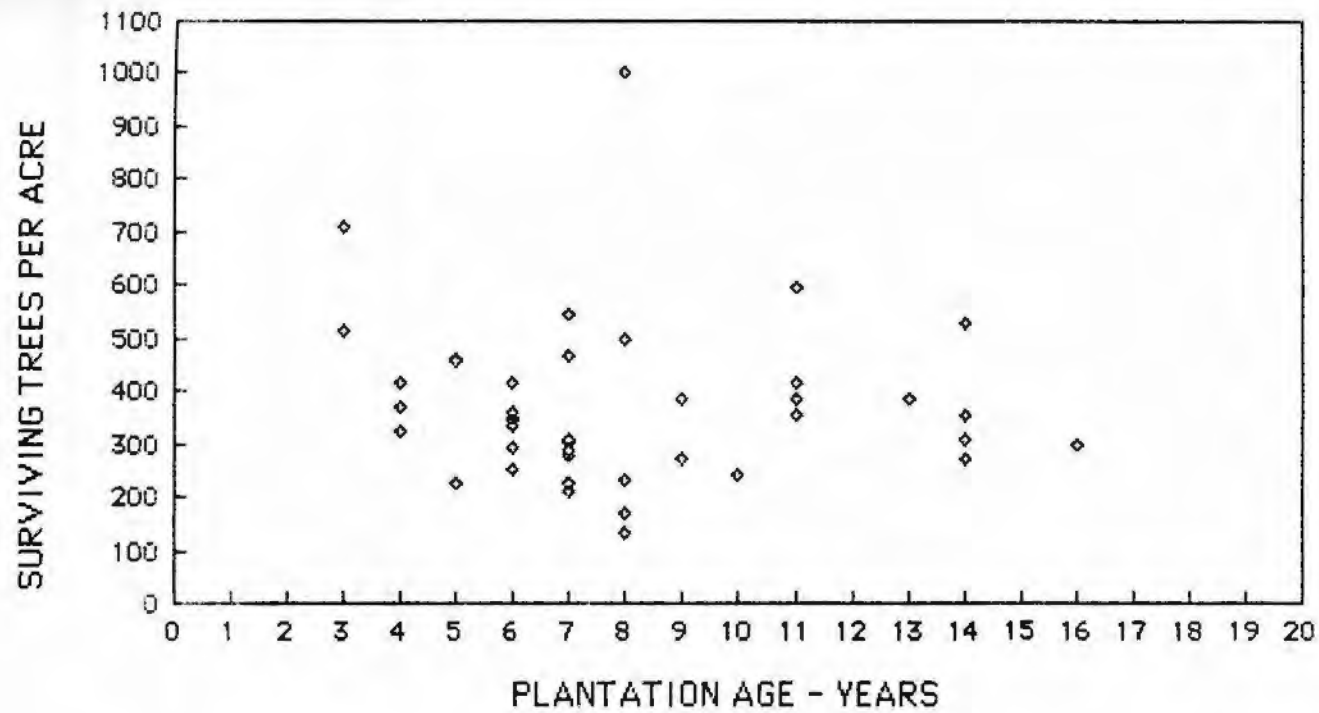
FIG. 4. NUMBER OF SLASH REGRESSION SUBPLOTS
BY TREES PER ACRE AND AGE.   n = 43 obs.

PREDICTING STAND STRUCTURE AND YIELD

After considering several possible methods of fitting the Weibull distribution to the data set, I decided to use the Weibull parameter recovery procedure developed by Burk and Burkhart (1984). The Burk and Burkhart method consists of:

1. Using stand values to estimate the minimum diameter, which is the location parameter of the Weibull distribution.
2. Using stand values to estimate the arithmetic mean diameter.
3. Using stand values to estimate the quadratic mean diameter.
4. Obtaining values for the scale and the shape parameters of the Weibull distribution through iterative procedures.

The complete system for predicting the stand structure and amount of wood per acre for slash pine plantations in East Texas is described in Figure 5.

Computer software written in FORTRAN or BASIC is available from the ETPPRP to generate diameter distributions for loblolly pine plantations in East Texas showing:

1. Number of trees per acre by diameter class.
2. Individual tree heights by diameter class.
3. Volume and weight per acre by diameter class.

Figure 5. A diameter distribution yield prediction system for slash pine plantations in East Texas.

---

1. Determine:

   a. Number of growing seasons completed since plantation establishment (A).

   b. Number of surviving trees per acre (T) at that age.

   c. Average total height of ten tallest trees (H) in plantation. If unknown, but site index (S) (base age = 25 years) is known, then predict H using:

   $$H = S((1-\exp(-0.07488801A))/0.846215)^{1.4502401} \qquad (1)$$

   (This equation was developed by Blackard 1986, 1985a and Lenhart et al. 1986)

2. Predict:

   a. Dbh of smallest tree (DMIN) in plantation, using:

   $$DMIN = -0.22481 + 0.06496H - 0.00126741T \qquad (2)$$
   $$(R^2 = 66\%)$$

   If DMIN is less than 0, DMIN = 0.

   b. Quadratic mean dbh (DQMEAN) for plantation, using:

   $$DQMEAN = 10^{(1.09600 - 11.70271(1/H) - 0.000162166T)} \qquad (3)$$
   $$(R^2 = 96\%)$$

   c. Arithmetic mean dbh (DMEAN) for plantation, using:

   $$DMEAN = -0.12272 + 0.99560DQMEAN \qquad (4)$$
   $$(r^2 = 99\%)$$

3. Compute the expected number of trees per acre for the plantation using the Weibull distribution. Weibull parameters are "recovered" with techniques developed by Burk and Burkhart (1984). The recovery process is:

    a. Location parameter (a) is equal to DMIN (Eq. 2).

    b. Shape parameter (c) is calculated by solving the following equation:

$$(DQMEAN)^2 - a^2 - 2a(DMEAN - a)$$

$$- (DMEAN - a)^2 \, \lceil (1 + 2/c)/ \, \lceil (1 + 1/c) = 0 \qquad (5)$$

    where: $\lceil$ = The complete gamma function.

    c. Scale parameter (b) is obtained using:

$$b = (DMEAN - a)/ \, \lceil (1 + 1/c) \qquad (6)$$

Computer software is available to solve Eq. 5 in an interative manner.

Solve the Weibull distribution to determine the proportion (P) of T in each dbh class as:

$$d_l < P < d_u = \exp(-((d_l - a)/b)^c) - \exp(-((d_u - a)/b)^c) \qquad (7)$$

    Where: d_l & d_u = lower & upper bound of diameter class.

Computer software can be easily developed to solve Eq. 7.

Multiply each P by T to obtain the expected number of trees per acre (n) in each dbh class.

4. Predict the total height (h) of each tree with dbh class mid-point dbh (d) (5.0, 6.0, etc.) using:

$$h = \exp(\ln(H) + 0.0045959 - 0.16604\ln(A)(\ln(DMAX) - \ln(d)$$

$$- 0.15172\ln(H/A)(\ln(DMAX) - \ln(d) \quad (8)$$

$$(R^2 = 69\%)$$

Where: DMAX = Dbh of largest tree in plantation.

(This equation developed by Blackard 1985b, 1986.)

5. Estimate the content (cubic feet, green weight, etc.) of the tree representing each dbh class mid-point.

An equation to estimate the cubic feet of wood (CFW) in a slash pine plantation in East Texas is:

$$CFW = 0.000838d^{1.859736}h^{1.301908} \quad (9)$$

$$(R^2 = 99\%)$$

(This equation developed by Hackett 1986.)

6. For the slash pine plantation, we now know:

    a. The number of trees per acre (n) for each dbh class.

    b. The cubic feet of wood per tree (CFW) for each dbh class.

Multiply CFW by n to obtain the cubic feet of wood per acre by dbh class.

Sum the CFW values across all dbh classes to determine the total cubic feet of wood per acre.

By selective summing across specified dbh classes, the CFW per acre by various tree size groups or different products (pulp, chip-n-saw, lumber, plywood, etc.) can be calculated.

The diameter distribution yield prediction system was evaluated using both the regression and evaluation subplots.

Regression Subplots. Plottings of the 43 residuals (predicted – observed volume) over stand parameters indicated underestimation on the older subplots. Plot of predicted volume over observed volume is shown in Figure 6. The underestimation on the higher volume subplots is evident. If only the 38 subplots with volume of 900 cubic feet per acre or less are considered, the system predicts in an unbiased manner.

Evaluation Suplots. In contrast to the regression subplots, plottings of the 43 residuals from the evaluation subplots over stand parameters indicated no bias or adverse trends. Figure 7 shows a plot of predicted volume over observed volume. If the three higher volume subplots are excluded, the average difference is only –13 cubic feet.

A detailed look at the ability of the yield prediction system to predict the number of trees per acre by dbh class and cubic feet of wood per acre by dbh class is presented for slash evaluation subplot 003 in Figures 8 and 9. The predicted trees per acre by dbh class match the observed trees per acre by dbh class very well, while the prediction of cubic feet of wood shows overprediction and underprediction.
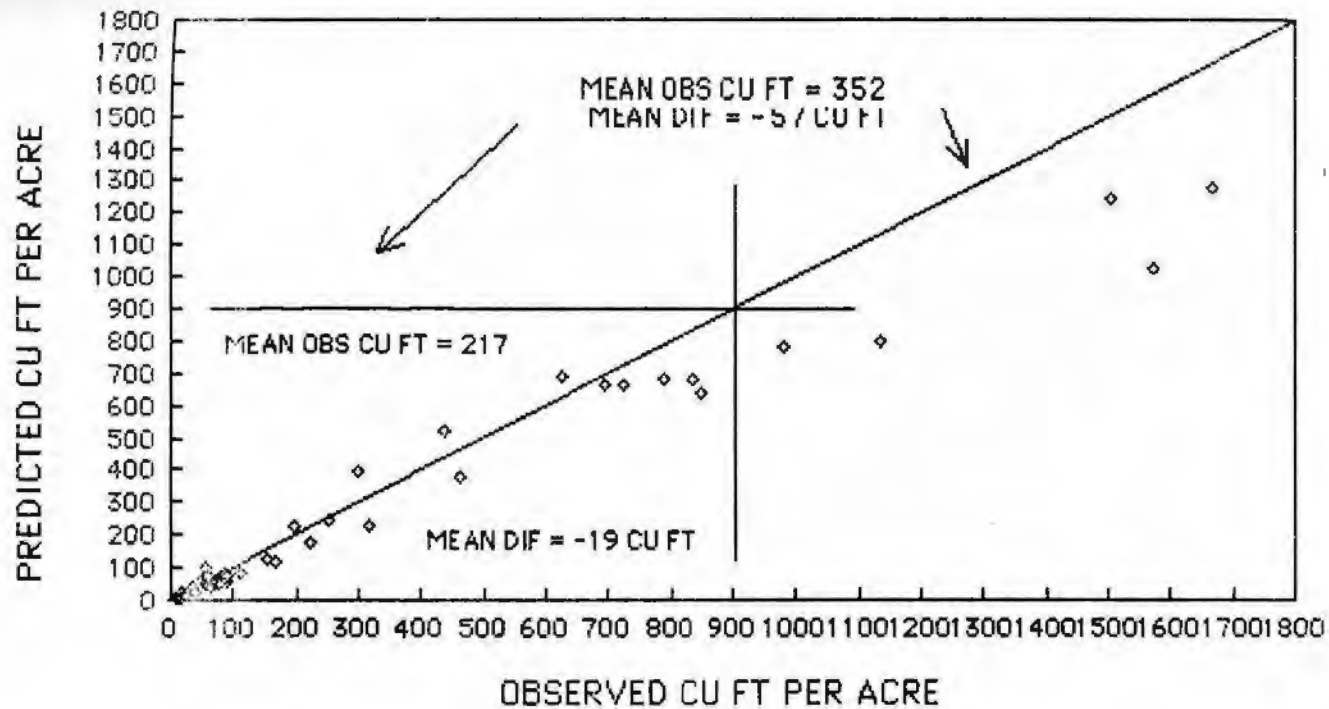
FIG. 6. PREDICTION PERFORMANCE
FOR SLASH REGRESSION SUBPLOTS.
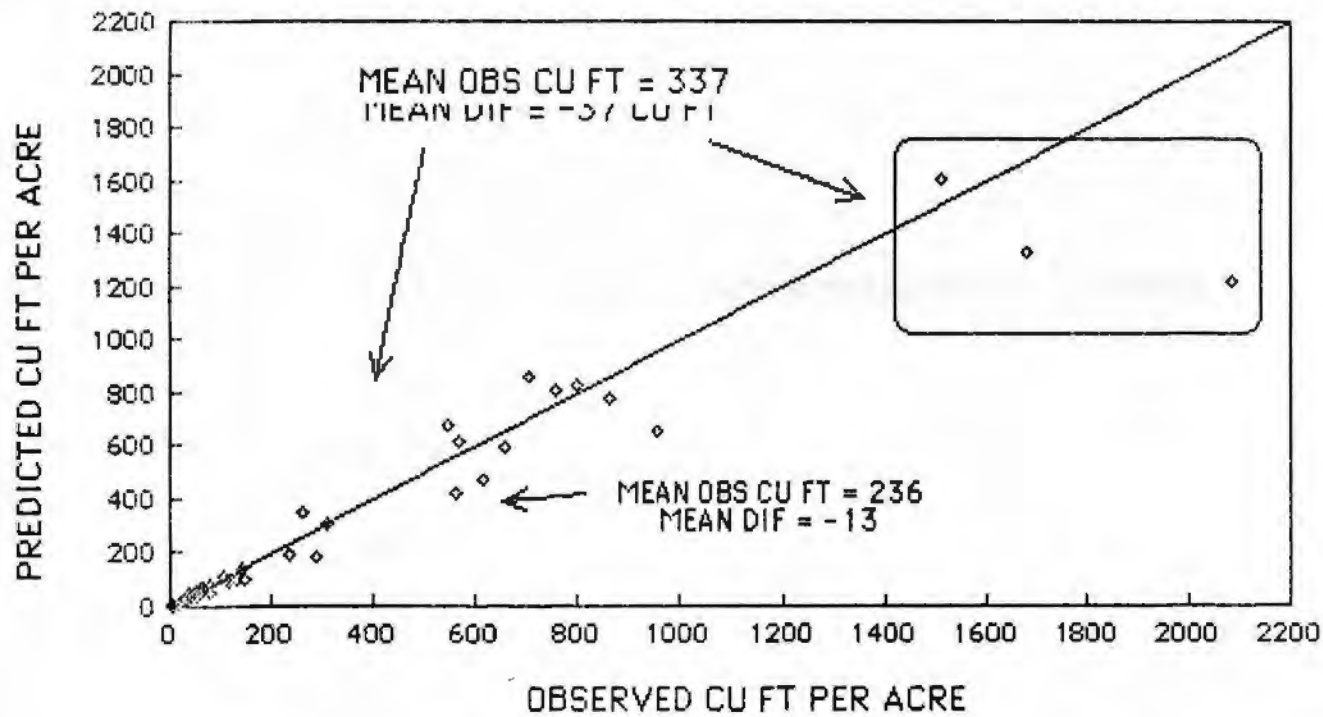
FIG. 7. PREDICTION PERFORMANCE
FOR SLASH EVALUATION SUBPLOTS.
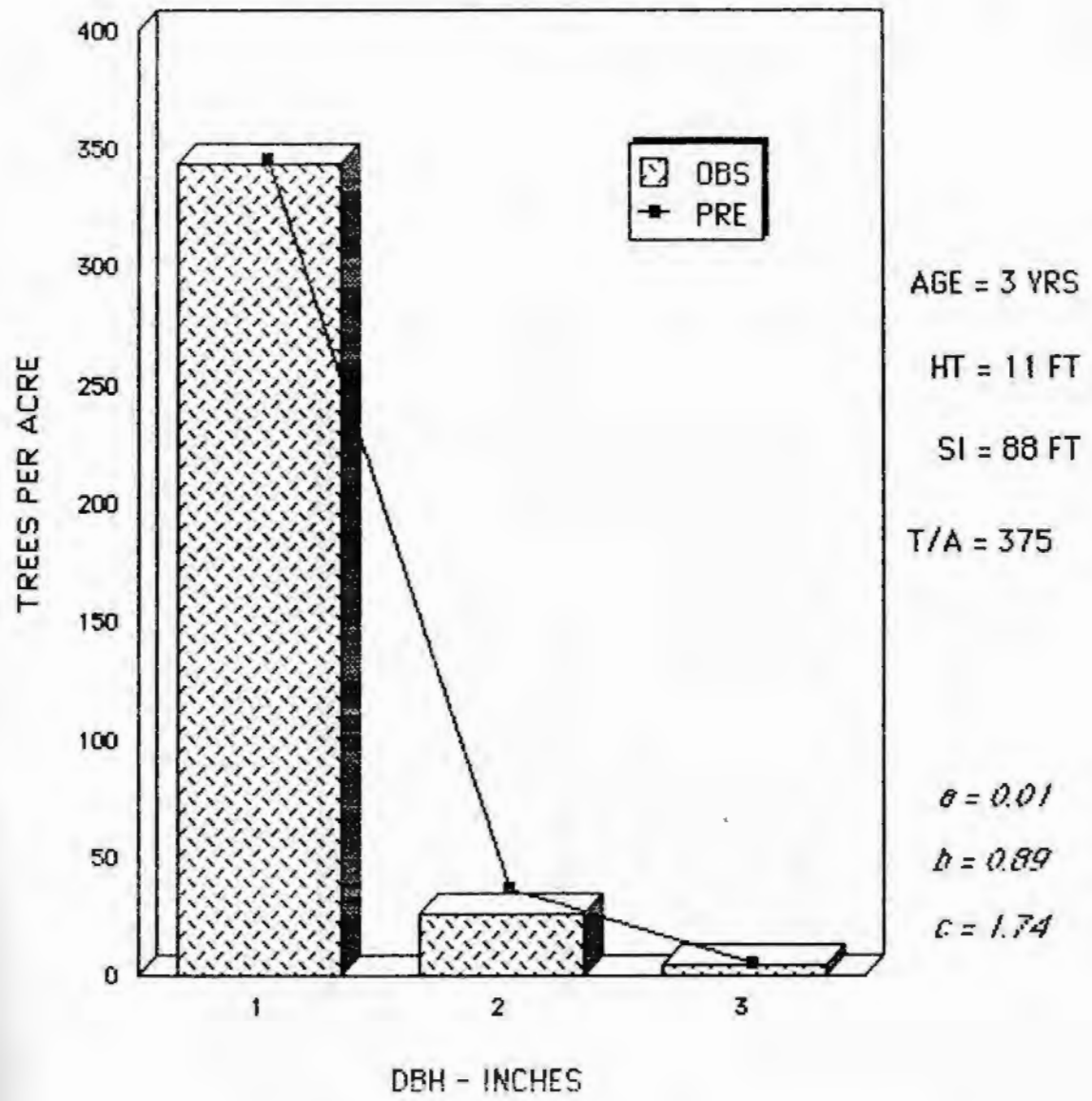
FIG. 8. OBSERVED T/A COMPARED TO PREDICTED T/A
FOR SLASH EVALUATION SUBPLOT 003.
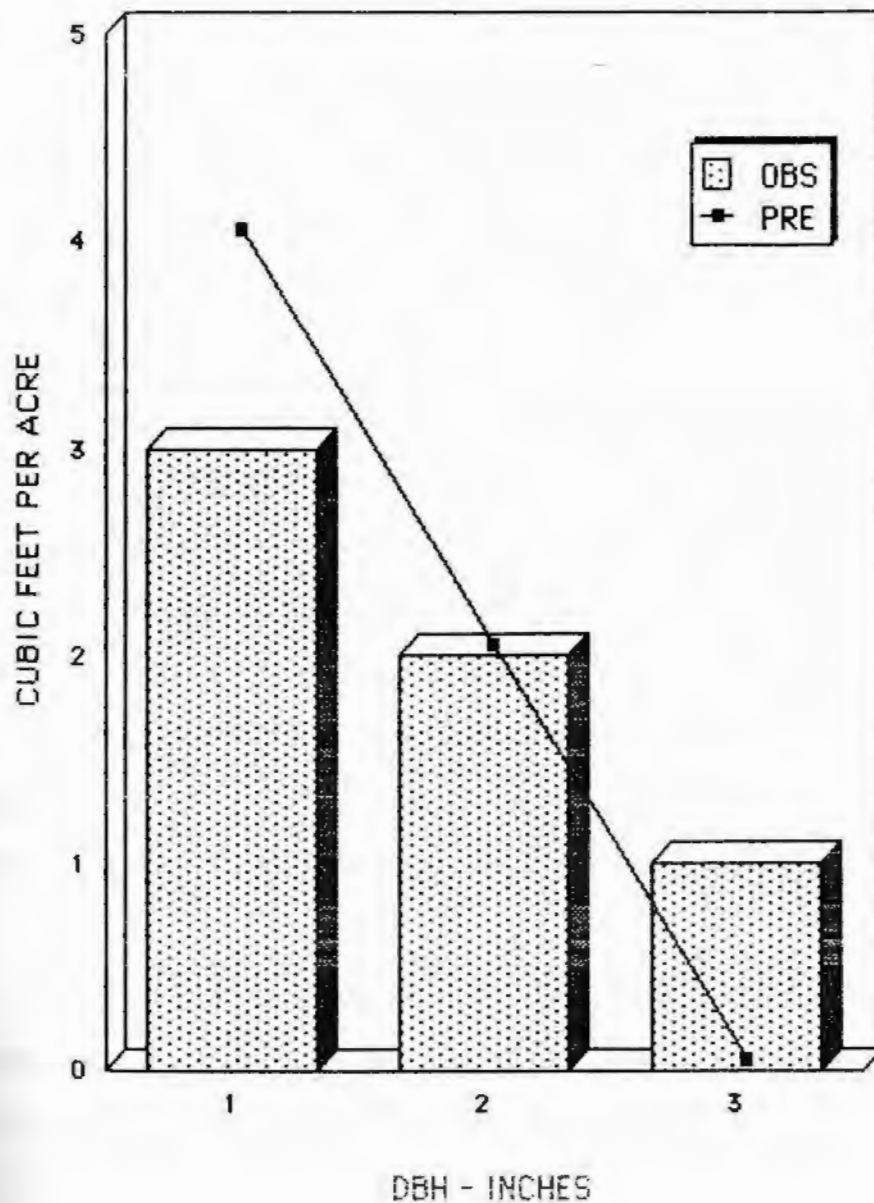
FIG. 9. OBSERVED CFW COMPARED TO PREDICTED CFW
FOR SLASH EVALUATION SUBPLOT 003.

An example of a set of yield curves is presented in Figure 10. Using the diameter distribution yield prediction system described in this report, the predicted cubic feet of wood per acre were generated using several combinations of site index and age, while holding surviving trees per acre constant. No information on stand structure is provided in Figure 10.

To demonstrate the ability of the system to predict details of the stand structure, as well as yield, the eleven tables following Figure 10 present information describing stands for site index value 70 and surviving trees per acre of 400. Plantation age varies from 4 to 24 years by 2 year increments. For each table, stand structure is described on a diameter class basis. The number of trees per acre, basal area, tree heights and four measures of yield are listed by diameter classes.

Stand structure information provides a forest manager the opportunity to determine the size characteristics of his planted trees and, thus, set different stumpage prices according to the expected tree utilization.

PLANTATION AGE - YEARS
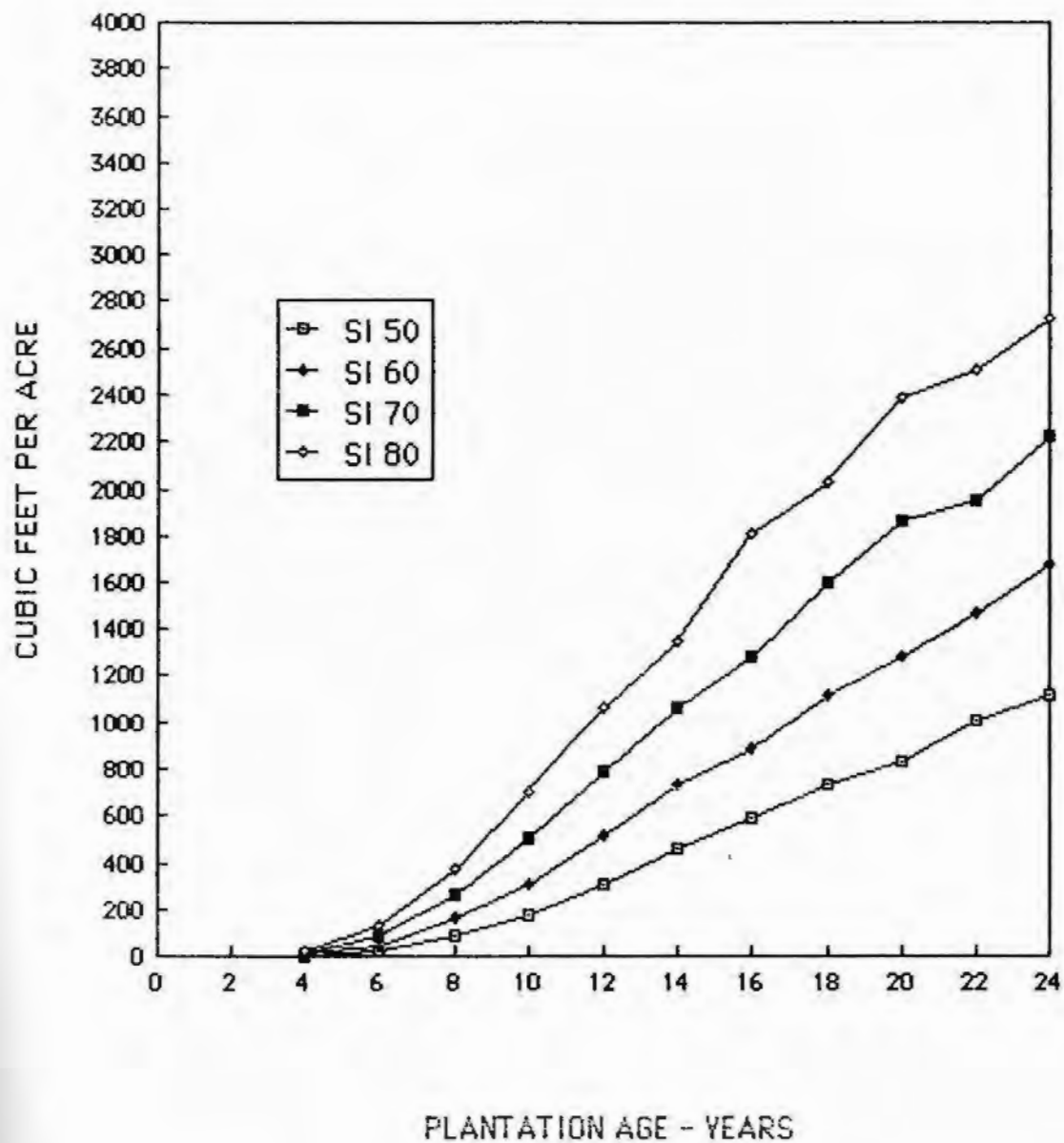
SLASH - 400 T/A

FIG. 10. PREDICTED CU FT WOOD PER ACRE.

PREDICTED
STAND STRUCTURE
PLUS
VOLUME AND WEIGHT PER ACRE BY DBH CLASS
FOR
SLASH PINE PLANTATIONS
ON
NON-OLD-FIELDS
IN
EAST TEXAS

```
*********************************************************
*           AGE =   4 YEARS SINCE ESTABLISHMENT     *
* SITE INDEX = 70 FEET (INDEX AGE = 25 YRS)         *
*           T/A =  400 SURVIVING AT AGE   4          *
*********************************************************
```

THREE PREDICTED PLANTATION CHARACTERISTICS ARE...
   1) AVERAGE HEIGHT OF TEN TALLEST TREES = 13 FEET.
   2) ARITHMETIC MEAN DBH = 1.2 INCHES.
   3) QUADRATIC MEAN DBH = 1.4 INCHES.

| | STRUCTURE | | AVG IND. | VOLUME & WEIGHT - TOTAL STEM | | | | |
| | | | | WOOD & BARK | | WOOD ONLY | | |
DBH (IN)	NUMBER OF TREES	BASAL AREA (SQFT)	TREE HT (FT)	VOLUME (CUFT)	GREEN WEIGHT (LBS)	VOLUME (CUFT)	DRY WEIGHT (LBS)	DBH (IN)
1	283	2	8	7	307	4	108	1
2	107	2	11	13	393	7	228	2
3	10	0	13	3	73	2	57	3
4	0	0	0	0	0	0	0	4
5	0	0	0	0	0	0	0	5
6	0	0	0	0	0	0	0	6
7	0	0	0	0	0	0	0	7
8	0	0	0	0	0	0	0	8
9	0	0	0	0	0	0	0	9
10	0	0	0	0	0	0	0	10
11	0	0	0	0	0	0	0	11
12	0	0	0	0	0	0	0	12
13	0	0	0	0	0	0	0	13
14	0	0	0	0	0	0	0	14
15	0	0	0	0	0	0	0	15
TOTAL	400	4		23	773	13	393	

PER ACRE VALUES

NOTE... BASED ON RESEARCH CONDUCTED IN THE
EAST TEXAS PINE PLANTATION RESEARCH PROJECT

SCHOOL OF FORESTRY
STEPHEN F. AUSTIN STATE UNIVERSITY
... BETWEEN 1982 - 1986.

```
                    PREDICTED
                        STAND STRUCTURE
                        PLUS
                        VOLUME AND WEIGHT PER ACRE BY DBH CLASS
                    FOR
                        SLASH PINE PLANTATIONS
                    ON
                        NON-OLD-FIELDS
                    IN
                        EAST TEXAS
```

```
    ***************************************************
    *           AGE = 10 YEARS SINCE ESTABLISHMENT    *
    * SITE INDEX = 70 FEET (INDEX AGE = 25 YRS)       *
    *           T/A =   400 SURVIVING AT AGE 10        *
    ***************************************************
```

THREE PREDICTED PLANTATION CHARACTERISTICS ARE...
    1) AVERAGE HEIGHT OF TEN TALLEST TREES = 35 FEET.
    2) ARITHMETIC MEAN DBH = 4.8 INCHES.
    3) QUADRATIC MEAN DBH = 5.0 INCHES.

------------------------- PER ACRE VALUES -------------------------

| | STRUCTURE | | | VOLUME & WEIGHT - TOTAL STEM | | | | |
| | | | AVG IND. | WOOD & BARK | | WOOD ONLY | | |
DBH (IN)	NUMBER OF TREES	BASAL AREA (SQFT)	TREE HT (FT)	VOLUME (CUFT)	GREEN WEIGHT (LBS)	VOLUME (CUFT)	DRY WEIGHT (LBS)	DBH (IN)
1	0	0	0	0	0	0	0	1
2	7	0	16	1	41	1	24	2
3	49	2	20	24	616	16	484	3
4	106	9	24	110	2354	73	2282	4
5	123	17	27	219	4122	150	4702	5
6	81	16	30	226	3844	159	5008	6
7	29	8	33	120	1861	86	2714	7
8	5	2	35	28	404	20	650	8
9	0	0	0	0	0	0	0	9
10	0	0	0	0	0	0	0	10
11	0	0	0	0	0	0	0	11
12	0	0	0	0	0	0	0	12
13	0	0	0	0	0	0	0	13
14	0	0	0	0	0	0	0	14
15	0	0	0	0	0	0	0	15
TOTAL	400	54		728	13242	505	15864	

PREDICTED
STAND STRUCTURE
PLUS
VOLUME AND WEIGHT PER ACRE BY DBH CLASS
FOR
SLASH PINE PLANTATIONS
ON
NON-OLD-FIELDS
IN
EAST TEXAS

```
***********************************************
*        AGE = 12 YEARS SINCE ESTABLISHMENT   *
*  SITE INDEX = 70 FEET (INDEX AGE = 25 YRS)  *
*        T/A =  400 SURVIVING AT AGE 12        *
***********************************************
```

THREE PREDICTED PLANTATION CHARACTERISTICS ARE...
    1) AVERAGE HEIGHT OF TEN TALLEST TREES = 42 FEET.
    2) ARITHMETIC MEAN DBH = 5.5 INCHES.
    3) QUADRATIC MEAN DBH = 5.7 INCHES.

```
------------------------------- PER ACRE VALUES ------------------------------
            STRUCTURE             VOLUME & WEIGHT - TOTAL STEM
        ---------------------     --------------------------------
                          AVG     WOOD & BARK          WOOD ONLY
                          IND.    ---------------     ---------------
        NUMBER   BASAL    TREE             GREEN                 DRY
 DBH      OF      AREA     HT     VOLUME  WEIGHT     VOLUME    WEIGHT     DBH
 (IN)   TREES   (SQFT)   (FT)    (CUFT)   (LBS)     (CUFT)     (LBS)     (IN)
 ----   ------  ------   ----    ------  ------     ------    ------     ----
  1        0       0       0        0        0         0          0        1
  2        1       0      17        0        6         0          4        2
  3       21       1      22       12      298         8        234        3
  4       69       6      26       79     1694        53       1646        4
  5      111      15      30      224     4246       155       4855        5
  6      107      21      33      335     5723       238       7472        6
  7       63      17      36      288     4509       209       6589        7
  8       22       8      39      140     2039       104       3284        8
  9        4       2      42       34      468        26        821        9
 10        0       0       0        0        0         0          0       10
 11        0       0       0        0        0         0          0       11
 12        0       0       0        0        0         0          0       12
 13        0       0       0        0        0         0          0       13
 14        0       0       0        0        0         0          0       14
 15        0       0       0        0        0         0          0       15
        ------  ------           ------  ------     ------    ------
TOTAL    400      70             1112    18983       793      24905
```

NOTE... BASED ON RESEARCH CONDUCTED IN THE
EAST TEXAS PINE PLANTATION RESEARCH PROJECT

SCHOOL OF FORESTRY
STEPHEN F. AUSTIN STATE UNIVERSITY
... BETWEEN 1982 - 1986.

PREDICTED
 STAND STRUCTURE
 PLUS
 VOLUME AND WEIGHT PER ACRE BY DBH CLASS
FOR
 SLASH PINE PLANTATIONS
ON
 NON-OLD-FIELDS
IN
 EAST TEXAS

```
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
*          AGE = 16 YEARS SINCE ESTABLISHMENT   *
* SITE INDEX = 70 FEET (INDEX AGE = 25 YRS)     *
*          T/A =   400 SURVIVING AT AGE 16       *
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

THREE PREDICTED PLANTATION CHARACTERISTICS ARE...
   1) AVERAGE HEIGHT OF TEN TALLEST TREES = 53 FEET.
   2) ARITHMETIC MEAN DBH = 6.3 INCHES.
   3) QUADRATIC MEAN DBH = 6.5 INCHES.

----------------------------- PER ACRE VALUES ----------------------------

| | STRUCTURE | | | VOLUME & WEIGHT - TOTAL STEM | | | | |
| | | | AVG IND. | WOOD & BARK | | WOOD ONLY | | |
DBH (IN)	NUMBER OF TREES	BASAL AREA (SQFT)	TREE HT (FT)	VOLUME (CUFT)	GREEN WEIGHT (LBS)	VOLUME (CUFT)	DRY WEIGHT (LBS)	DBH (IN)
1	0	0	0	0	0	0	0	1
2	0	0	0	0	0	0	0	2
3	4	0	23	2	60	2	47	3
4	35	3	28	44	943	30	918	4
5	80	11	32	174	3319	122	3800	5
6	107	21	36	371	6383	267	8351	6
7	94	25	40	487	7680	358	11246	7
8	54	19	43	387	5657	290	9131	8
9	20	9	47	196	2693	150	4738	9
10	5	3	50	64	824	49	1566	10
11	1	1	53	16	196	13	404	11
12	0	0	0	0	0	0	0	12
13	0	0	0	0	0	0	0	13
14	0	0	0	0	0	0	0	14
15	0	0	0	0	0	0	0	15
TOTAL	400	92		1741	27757	1281	40201	

NOTE...   BASED ON RESEARCH CONDUCTED IN THE
         EAST TEXAS PINE PLANTATION RESEARCH PROJECT

                    SCHOOL OF FORESTRY
                    STEPHEN F. AUSTIN STATE UNIVERSITY
                    ... BETWEEN 1982 - 1986.

PREDICTED
STAND STRUCTURE
PLUS
VOLUME AND WEIGHT PER ACRE BY DBH CLASS
FOR
SLASH PINE PLANTATIONS
ON
NON-OLD-FIELDS
IN
EAST TEXAS

```
****************************************************
*            AGE = 22 YEARS SINCE ESTABLISHMENT  *
* SITE INDEX = 70 FEET (INDEX AGE = 25 YRS)      *
*        T/A =  400 SURVIVING AT AGE 22          *
****************************************************
```

THREE PREDICTED PLANTATION CHARACTERISTICS ARE...
1) AVERAGE HEIGHT OF TEN TALLEST TREES = 65 FEET.
2) ARITHMETIC MEAN DBH = 6.9 INCHES.
3) QUADRATIC MEAN DBH = 7.1 INCHES.

----------------------------- PER ACRE VALUES -----------------------------

| | STRUCTURE | | | VOLUME & WEIGHT - TOTAL STEM | | | | |
| | | | AVG IND. | WOOD & BARK | | WOOD ONLY | | |
DBH (IN)	NUMBER OF TREES	BASAL AREA (SQFT)	TREE HT (FT)	VOLUME (CUFT)	GREEN WEIGHT (LBS)	VOLUME (CUFT)	DRY WEIGHT (LBS)	DBH (IN)
1	0	0	0	0	0	0	0	1
2	0	0	0	0	0	0	0	2
3	0	0	0	0	0	0	0	3
4	13	1	31	18	393	13	388	4
5	56	8	36	140	2693	99	3092	5
6	94	18	41	380	6602	277	8662	6
7	101	27	45	601	9567	448	14046	7
8	75	26	50	642	9495	489	15376	8
9	40	18	54	463	6410	359	11315	9
10	15	8	58	228	2978	180	5678	10
11	4	3	62	78	966	62	1976	11
12	1	1	65	24	284	20	612	12
13	0	0	0	0	0	0	0	13
14	0	0	0	0	0	0	0	14
15	0	0	0	0	0	0	0	15
TOTAL	400	110		2574	39393	1947	61152	

NOTE... BASED ON RESEARCH CONDUCTED IN THE
EAST TEXAS PINE PLANTATION RESEARCH PROJECT

SCHOOL OF FORESTRY
STEPHEN F. AUSTIN STATE UNIVERSITY
... BETWEEN 1982 - 1986.

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