Tree Volume Equations and Tables from Dendrometer Measurements

I. Tree Volume Equations from Measurements Taken with a Barr and Stroud Optical Dendrometer
   Lee C. Wensel

II. Young Growth Gross Volume Tables for Sierra Redwood
   \{Sequoia gigantea\} (Lindl.) Decne
   Lee C. Wensel and Richard L. Schoenheide
In the first paper, the procedures are developed to compute tree volume equations from field measurements taken with a Barr and Stroud optical dendrometer. The computer programs used to perform all of the calculations are briefly described. The volume equations developed for young growth Sierra redwood are also reported, together with a discussion of the validity of these equations.

In the second paper, tree volume tables are given for young growth Sierra redwood based upon measurements taken at Mountain Home State Forest. Standard and local volume tables are given for cubic feet and Scribner board feet, together with the 95 per cent confidence intervals for the volumes in these tables. The standard table for cubic feet is based upon total height while for Scribner board feet tables are given for both merchantable height (6-inch top) and total height.

THE AUTHORS:
Lee C. Wensel is Assistant Professor of Forestry, University of California, Berkeley.

Richard L. Schoenheide is Forest Manager, Mountain Home State Forest, Springville, California.
I. Tree Volume Equations from Measurements Taken with a Barr and Stroud Optical Dendrometer

INTRODUCTION

The virtues of using optical devices in forest inventory have been widely documented by numerous authors. In the United States, Grosenbaugh (1963) has pioneered the use of optical devices, including the use of the Barr and Stroud dendrometer which is of concern here. Grosenbaugh (1967) has developed a computer program called STX that can be used to convert the dendrometer measurements to tree diameter, height, surface area, and volume.

Bell and Groman (1971) have reported on tests of the Barr and Stroud Type FP-12 optical dendrometer, the type used in the present study, concluding that "upper-stem diameters and segment lengths determined with the Barr and Stroud optical dendrometer are highly accurate under field conditions." They found that the accuracy in measuring tree diameters varied from 2 to 3 per cent. The accuracy in measuring stem lengths varied from about 1 per cent at elevations of about 23 feet to about 4 per cent at elevations of about 63 feet.

In connection with appropriate sampling techniques and the computer program STX (Grosenbaugh 1967), the Barr and Stroud optical dendrometer can be used to obtain volume estimates in a forest inventory without the use of volume tables. However, relatively few foresters have access to a Barr and Stroud dendrometer and a computer. Thus volume tables are still necessary. Even those foresters who do have access to a dendrometer still require volume tables in much of their work.

The procedures and programs presented here detail the procedures that one would use to construct standard (based upon tree DBH and height) and local (based upon tree DBH only) volume tables for any species. However, the following discussion details the application of these procedures to the tables that appear in the second paper for young growth Sierra redwood, a species for which no volume tables have previously existed.

Volume Computations

Sample trees are randomly located within the range of the tree diameters to be considered. The measurements to be collected for each tree consist of DBH measured with a diameter tape, double bark thickness at breast height, measured at two locations at right angles to each other, and dendrometer readings taken at various points on each tree. All of the data is recorded on field forms prepared by Grosenbaugh (1967) and the dendrometer readings are con-
verted to tree diameters and heights by program STX. Diameter inside bark measurements were obtained using the ratio of the inside to outside bark diameters at breast height. The cubic-foot tree volumes are obtained from the “tree detail” cards punched by program STX. The necessary control cards for STX, and a sample set of data for three trees, appears in Appendix A.

The Scribner board-foot tree volumes are computed by program BFVOL (Appendix B). This program uses the “log detail” cards produced by STX as its basic data and computes the Scribner board foot volume by reducing the tree to individual logs.

The merchantable height to a six-inch top, \( H_G \), was obtained by the interpolation equation

\[
H_G = H_{d_1} + (H_{d_2} - H_{d_1}) \frac{6^2 - d_2^2}{d_2^2 - d_1^2}
\]  

(1)

where \( d \) is the diameter inside bark, \( d_1 \geq 6 \) and \( d_2 < 6 \), and \( H_{d_1} \) and \( H_{d_2} \) are the corresponding heights.

Using the subroutine LOGS, the merchantable tree length is divided up into logs following the scaling rules used by the California Division of Forestry. Within each tree the log lengths varied from 10 to 20 feet, and were as alike as possible (see sample output from BFVOL, Appendix table B-2). Appropriate changes can be made in subroutine LOGS to use any scaling rule desired.

The scaling diameter \( d \) for each log is given by

\[
d = \frac{h_1 d_2^2 + h_2 d_1^2}{h_1 + h_2}
\]

(2)

where \( d_1, d_2, h_1 \) and \( h_2 \) are the tree diameter (inside bark) and heights, respectively, as shown in figure 1. The symbol \( h \) stands for the actual length of the log (nominal length plus trim allowance).

The bark thickness, \( b_i \), needed to convert the diameter outside bark at point \( i, D_i \), to diameter inside bark, \( d_i \), is obtained from the relationship

\[
b_i = b_{DBH} \left( \frac{D_i}{DBH} \right)
\]

(3)

where \( b_{DBH} \) is the bark thickness measured at breast height with a bark guage. Program STX allows for bark ratios other than \((D_i/DBH)\) if this ratio seems inappropriate in a given application.

The Scribner board-foot volume \( V \) is calculated for each log, altering the equation for 16 foot logs (Bruce and Schumacher, 1950) by the ratio of the actual length divided by 16 feet, as follows

\[
V = \frac{\log \text{length}}{16} (0.79 d^2 - 2d - 4)
\]

(4)

Volume regressions

Once all of the volumes have been computed, the cubic-foot volumes by program STX and the Scribner board-foot volumes by program BFVOL, a

---

STX was modified to punch an extra data card for each tree giving the diameter at the large end of the first log.
series of regression equations must be computed. The models that were chosen here have been found to give a good fit (high \( R^2 \) and well behaved at the end points) and satisfy the usual assumptions of equal variances and normal errors.

For the Sierra redwood data, program DANIEL\(^*\) was used to fit the logarithmic form of the form factor volume equation:

\[
\log V = b_0 + b_1 \log d + b_2 \log h \tag{5}
\]

to both the board-foot and cubic-foot data, where \( d \) is the tree DBH and \( h \) is the tree height and \( b_0, b_1, b_2 \) are the constants to be fitted. Then, recognizing the exponential relationship that exists between tree diameter and tree height (Meyer, 1940), the term \( \log h \) was replaced by \( d \) in equation (5) to yield the local volume equation (6)

\[
\log V = b_0 + b_1 \log d + b_2 d \tag{6}
\]

All logarithms are natural logarithms, i.e., to the base \( e \).

Below are listed the coefficients for equations (5) and (6). For equation (5), which is termed a “standard” volume function because it includes terms for both tree DBH and tree height, coefficients are listed for cubic feet (total height) and Scribner board feet (merchantable height and total height). As measured by \( R^2 \), the coefficient of multiple determination, the equations all fit well, accounting for a high percentage of the total variation in each case.

<table>
<thead>
<tr>
<th>Equation (5) coefficients</th>
<th>Cubic feet (total height)</th>
<th>Board feet (merch. height)</th>
<th>Board feet (total height)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( b_0 )</td>
<td>-6.66790</td>
<td>-5.20645</td>
<td>-5.66831</td>
</tr>
<tr>
<td>( b_1 )</td>
<td>1.54423</td>
<td>1.22817</td>
<td>2.21035</td>
</tr>
<tr>
<td>( b_2 )</td>
<td>1.29808</td>
<td>1.62977</td>
<td>0.91921</td>
</tr>
<tr>
<td>( R^2 )</td>
<td>.958</td>
<td>.973</td>
<td>.908</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Equation (6) coefficients</th>
<th>Cubic feet</th>
<th>Board feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>( b_0 )</td>
<td>-4.43275</td>
<td>-6.54770</td>
</tr>
<tr>
<td>( b_1 )</td>
<td>2.85186</td>
<td>4.21450</td>
</tr>
<tr>
<td>( b_2 )</td>
<td>-0.01911</td>
<td>-0.05073</td>
</tr>
<tr>
<td>( R^2 )</td>
<td>.921</td>
<td>.888</td>
</tr>
</tbody>
</table>

To examine the reasonableness of the regression assumptions, the residuals are plotted by program DANIEL. For the Sierra redwood data, the results of these plots were quite similar and the plots for the cubic-foot equation (5) are given in figures 2 and 3.

Figure 2 gives the cumulative plot of the residuals on the cubic-foot data, with the ordinate axis on a logarithmic scale. To meet the necessary assumption of normality of the residuals, these data should plot approximately as a straight line through the point \((0.5, 0)\). As evidenced by figure 2, the normality assumption appears to hold reasonably well.

Figure 3 gives the plot of the residuals on the fitted volumes for the same equation. A pattern that shows a relationship between the residuals and the fitted volumes indicates a violation of the assumptions of independence and homogeneity of variance. Since the points in figure 3 show no clear pattern, this plot supports the assumptions made.

Volume tables can then be listed using the equations developed here. The volume tables for young growth Sierra redwood are available from the University of California Computer Center Library, Berkeley.

\(^*\) Program and instructions are available from the University of California Computer Center Library, Berkeley.
redwood appear in the second paper. The computer programs used to list these tables are available from the author.

The 95 per cent confidence limits for any volume in the table can be obtained from the relationship

\[ E_i = \frac{e^{\log V + 1.96\sigma} - e^{\log V - 1.96\sigma}}{e^{\log V}} \]  

(7)

which reduces to

\[ E_i = e^{1.96\sigma} - e^{-1.96\sigma} \]  

(8)

where \( E_i \) is the confidence interval (in per cent) corresponding to a tree of diameter \( D_i \) at breast height and a height of \( H_i \) feet, 1.96 is the .95 probability point from the normal distribution,\(^4\)

\(^4\) Draper and Smith (1966), p. 121.
Fig. 3. Residuals on fitted volumes for cubic foot equation (1).

\[ \hat{\sigma} = \text{mean} \sqrt{Y_i (X'X)^{-1} Y_i'} \]  \hspace{1cm} (9)

\[ X = \begin{bmatrix} 1 & \log D_1 & \log H_1 \\ 1 & \log D_2 & \log H_2 \\ \vdots & \vdots & \vdots \\ 1 & \log D_{195} & \log H_{195} \end{bmatrix} \]  \hspace{1cm} (10)

\[ Y'_i = \begin{bmatrix} 1 \\ \log D_i \\ \log H_i \end{bmatrix} \]  \hspace{1cm} (11)

The confidence interval for \( \log V \) is symmetric (±1.96 \( \hat{\sigma} \)) about the volume estimate. Also, because of their independence, the variances (\( \hat{\sigma}^2 \)) are additive, i.e., the confidence interval for \( \log V_1 + \log V_2 \) is ±1.96 \( \hat{\sigma}_1^2 + \hat{\sigma}_2^2 \).
Because of the nature of the logarithmic transformation, it is not possible to do the same thing with the untransformed values of $V$ and $\sigma$ and still have unbiased estimates of the confidence intervals. However, in dealing with a group of trees all about the same size, the arithmetic mean and the geometric mean (mean of logarithms) will be about the same. Under this situation, the bias would probably be small and the width of the confidence intervals for $V_1 + V_2 + \cdots + V_n$ can be estimated by $\pm 1.96 n \sqrt{\bar{E}_1 \bar{E}_2 \cdots \bar{E}_n}$.

The exact confidence interval is extremely complex and has never been worked out, although Naus (1969) has worked out the distribution for the sum of two log-normal variables.

**APPENDIX A: Data Card Preparation for Program STX.**

**APPENDIX A**

**TABLE A-1**

<table>
<thead>
<tr>
<th>SAMPLE DATA CARDS FOR STX PROGRAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOUNTAIN HOME STATE FOREST -- GIANT SEQUOIA VOLUME STUDY</td>
</tr>
<tr>
<td>LCW</td>
</tr>
<tr>
<td>MHSF</td>
</tr>
</tbody>
</table>

**TABLE A-2**

<table>
<thead>
<tr>
<th>SAMPLE OUTPUT FROM STX, TREE DETAIL CARDS USED</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOUNTAIN HOME STATE FOREST -- GIANT SEQUOIA VOLUME STUDY</td>
</tr>
</tbody>
</table>

**DETAILED LOG AND/OR TREE REPORT**

**NO. / CFRT. / FT. / CODE / FEET / TGRADS / FGRADS SINELV**
Table A-3
SAMPLE PUNCHED CARD OUTPUT FROM STX, TREE DETAIL CARDS USED AS INPUT TO BFVOL

<table>
<thead>
<tr>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
<th>(7)</th>
<th>(8)</th>
<th>(9)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11111</td>
<td>38.6</td>
<td>133.4</td>
<td>1133.4</td>
<td>4</td>
<td>2.0</td>
<td>22.4</td>
<td>25.9</td>
<td>1.000</td>
</tr>
<tr>
<td>11011</td>
<td>38.6</td>
<td>133.4</td>
<td>6.9107.5</td>
<td>5.7</td>
<td>9.7</td>
<td>53.2</td>
<td>23.6</td>
<td>1.000</td>
</tr>
<tr>
<td>191</td>
<td>38.6</td>
<td>133.4</td>
<td>10.7</td>
<td>83.8</td>
<td>8.5</td>
<td>32.3</td>
<td>9.8</td>
<td>1.000</td>
</tr>
<tr>
<td>181</td>
<td>38.6</td>
<td>133.4</td>
<td>14.5</td>
<td>74.1</td>
<td>13.0</td>
<td>41.2</td>
<td>10.4</td>
<td>1.000</td>
</tr>
<tr>
<td>171</td>
<td>38.6</td>
<td>133.4</td>
<td>15.8</td>
<td>63.7</td>
<td>14.7</td>
<td>40.1</td>
<td>8.7</td>
<td>1.000</td>
</tr>
<tr>
<td>161</td>
<td>38.6</td>
<td>133.4</td>
<td>19.4</td>
<td>55.0</td>
<td>45.8</td>
<td>108.9</td>
<td>20.6</td>
<td>1.000</td>
</tr>
<tr>
<td>151</td>
<td>38.6</td>
<td>133.4</td>
<td>21.0</td>
<td>34.4</td>
<td>24.5</td>
<td>54.6</td>
<td>9.7</td>
<td>1.000</td>
</tr>
<tr>
<td>141</td>
<td>38.6</td>
<td>133.4</td>
<td>22.1</td>
<td>24.7</td>
<td>22.5</td>
<td>45.7</td>
<td>7.4</td>
<td>1.000</td>
</tr>
<tr>
<td>131</td>
<td>38.6</td>
<td>133.4</td>
<td>25.0</td>
<td>17.3</td>
<td>37.3</td>
<td>64.3</td>
<td>8.8</td>
<td>1.000</td>
</tr>
<tr>
<td>121</td>
<td>38.6</td>
<td>133.4</td>
<td>30.6</td>
<td>8.5</td>
<td>81.8</td>
<td>92.4</td>
<td>8.5</td>
<td>1.000</td>
</tr>
<tr>
<td>111</td>
<td>38.6</td>
<td>133.4</td>
<td>52.6</td>
<td>0.</td>
<td>0.</td>
<td>0.</td>
<td>0.</td>
<td>1.000</td>
</tr>
<tr>
<td>211</td>
<td>16.0</td>
<td>50.4</td>
<td>1.1</td>
<td>50.4</td>
<td>2.4</td>
<td>24.6</td>
<td>26.2</td>
<td>1.000</td>
</tr>
<tr>
<td>211</td>
<td>16.0</td>
<td>50.4</td>
<td>7.1</td>
<td>24.2</td>
<td>2.7</td>
<td>16.4</td>
<td>8.0</td>
<td>1.000</td>
</tr>
<tr>
<td>211</td>
<td>16.0</td>
<td>50.4</td>
<td>9.7</td>
<td>16.7</td>
<td>4.4</td>
<td>21.3</td>
<td>8.2</td>
<td>1.000</td>
</tr>
<tr>
<td>211</td>
<td>16.0</td>
<td>50.4</td>
<td>11.1</td>
<td>7.9</td>
<td>8.1</td>
<td>28.3</td>
<td>7.9</td>
<td>1.000</td>
</tr>
<tr>
<td>211</td>
<td>16.0</td>
<td>50.4</td>
<td>15.2</td>
<td>0.0</td>
<td>0.</td>
<td>0.</td>
<td>0.</td>
<td>1.000</td>
</tr>
<tr>
<td>311</td>
<td>14.8</td>
<td>55.2</td>
<td>1.1</td>
<td>55.2</td>
<td>3.3</td>
<td>38.7</td>
<td>30.3</td>
<td>1.000</td>
</tr>
<tr>
<td>311</td>
<td>14.8</td>
<td>55.2</td>
<td>7.6</td>
<td>24.9</td>
<td>3.4</td>
<td>15.9</td>
<td>8.4</td>
<td>1.000</td>
</tr>
<tr>
<td>311</td>
<td>14.8</td>
<td>55.2</td>
<td>9.5</td>
<td>16.5</td>
<td>5.3</td>
<td>23.9</td>
<td>8.7</td>
<td>1.000</td>
</tr>
<tr>
<td>311</td>
<td>14.8</td>
<td>55.2</td>
<td>11.6</td>
<td>7.7</td>
<td>7.3</td>
<td>26.6</td>
<td>7.8</td>
<td>1.000</td>
</tr>
<tr>
<td>311</td>
<td>14.8</td>
<td>55.2</td>
<td>14.6</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>1.000</td>
</tr>
<tr>
<td>(1) Tree number</td>
<td>(2) Log number</td>
<td>(3) DBH</td>
<td>(4) Total height of tree in feet</td>
<td>(5) Diameter inside bark in inches</td>
<td>(6) Height above base of tree in feet</td>
<td>(7) Cubic foot volume of log</td>
<td>(8) Surface area in square feet</td>
<td>(9) Log length in feet</td>
</tr>
</tbody>
</table>

Table A-4
SAMPLE OUTPUT FROM PROGRAM STX, TREE DETAIL CARDS USED FOR REGRESSION

<table>
<thead>
<tr>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
<th>(7)</th>
<th>(8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>111</td>
<td>38.6</td>
<td>4.3</td>
<td>-0</td>
<td>260.2</td>
<td>555.1133.4</td>
<td>1.000</td>
<td>8.126</td>
</tr>
<tr>
<td>211</td>
<td>16.0</td>
<td>1.9</td>
<td>-0</td>
<td>17.6</td>
<td>90.6</td>
<td>50.4</td>
<td>1.000</td>
</tr>
<tr>
<td>311</td>
<td>14.8</td>
<td>1.7</td>
<td>-0</td>
<td>19.2</td>
<td>100.1</td>
<td>55.2</td>
<td>1.000</td>
</tr>
<tr>
<td>(1) Tree number</td>
<td>(2) DBH</td>
<td>(3) Double bark</td>
<td>(4) Vol cu ft</td>
<td>(5) Surface area</td>
<td>(6) Height</td>
<td>(7) BA</td>
<td>(8) Vol bd ft</td>
</tr>
</tbody>
</table>

* Used in regression by program DANIEL.
APPENDIX B: Program BFVOL

APPENDIX B

PROGRAM BFVOL LISTING. PROGRAM COMPUTES THE SCRIBNER BOARD FOOT VOLUMES FROM TREE DETAIL INFORMATION OBTAINED FROM PROGRAM STX

```plaintext
PROGRAM BFVOL(INPUT,OUTPUT,PUNCH)  1
DIMENSION DIB(20), TL(20)  2
DIMENSION D(20), DBHU(196), HMER(196), IRV(196), N(196)  3
COMMON /LOGS/ L(10), NLOGS, TPEEL, LOGL  .4
PRINT  190 5
K=1
I=0
10 I=I+1
READ 140, N(K), NB, DBH(K), DIR(I), TL(I)
IF (N(K).EQ.1000) GO TO 120
IF (NB.NE.1) GO TO 10
IF (NB.NE.1) GO TO 10
12 C TO FIND MERCH. HEIGHT WITH THE TOP OF 6-INCH DIR.
J=1
20 IF (DIB(J).LT.6. AND. DIB(J*I).GE.6.) GO TO 30
J=J*I
GO TO 20
30 IF (DIB(J*I).EQ.6.) GO TO 40
TREEL=TL(J*(I-1))-((36.-DIR(I)**2)/(DIR(I)**2-DIR(I)**2-(I-1))
40 TREEL=TL(J*I)
50 CALL LOGS
C TO FIND SCALING DIAMETERS.
NL=NLOGS
M=1
SUM=0.
60 SUM=SUM-L(NL)*0.5
70 IF (SUM.GE.TL(I).AND.SUM.LT.TL(I-1)) GO TO 80
I=I-1
GO TO 70
80 IF (SUM.GQ.TL(I)) GO TO 90
D(M)=SORT(((TL(I-1)-SUM)*DIR(I)**2*(SUM-TL(I))*DIR(I)**2)/(TL(I-1)-TL(I))
90 D(M)=DIB(T)
100 NL=NL-1
M=M*I
IF (NL.NE.0) GO TO 60
C TO FIND BOARD FOOT VOLUME
C V = (.79*PJ - 2D - 4) * L/16.
V=0.
JJ=NLOGS
DO 110  II=1,NLOGS
V=V*(.79*n(II)*2-2*PJ-4)*L(JJ)/16.
JJ=JJ-1
110 CONTINUE
IRV(K)=V
HMER(K)=TREEL
IF (K.NE.51.OR.K.EQ.101.OR.K.EQ.151) PRINT 190
190 PRINT 180, N(K), TPEEL, LOGL, NLOGS, (L(J), J^ltNLOGS)
K=K+1
GO TO 10
120 K=K-1
PRINT 180
DO 130  I=1,K
IF (K.FQ.51.OR.K.EQ.101.OR.K.EQ.151) PRINT 150
130 CONTINUE
STOP
```

Wensel: Tree Volume Equations
APPENDIX B—Table B-1 Continued

SUBROUTINE LOGS
COMMON /LOGS/ L(10), NLOGS, TREE, LOGL

DO 10 I=1,10
L(I)=0

10 IF (NLOGS.GT.10) PRINT 130, NLOGS
GO TO 110

20 L(I)=(LOGL/NLOGS/2)**2
IF (L(I).EQ.20) GO TO 30
IF (NLOGS.LT.L(I)) GO TO 50

30 DO 40 J=2, I
L(J)=L(I)
40 CONTINUE

50 N=NLOGS-1

DO 60 J=1, N
IF (NLOGS.LT.L(J)) GO TO 70

60 CONTINUE
PRINT 120, NLOGS, LOGL, L(I)
GO TO 110

70 IF (I.EQ.1) GO TO 90

DO 80 J=2, I
L(J)=L(I)
80 CONTINUE

90 RETURN

120 FORMAT (3H ERROR IN CALCULATING LOG LENGTHS,/5X,7H NLOGS =, I3,5X/6
ILOGL =I3,5X,6H L(1) =, I3)
END

TABLE B-2
BFVOL OUTPUT. LISTING OF TREE VOLUME AND HEIGHT INFORMATION

<table>
<thead>
<tr>
<th>Tree number</th>
<th>DBH inches</th>
<th>Merch. height feet</th>
<th>Scale</th>
<th>Logs number</th>
<th>Log length feet</th>
<th>Merch. volume bd. ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>38.6</td>
<td>111.3</td>
<td>108</td>
<td>6</td>
<td>18</td>
<td>18 18 18 18 18</td>
</tr>
<tr>
<td>2</td>
<td>16.0</td>
<td>31.7</td>
<td>20</td>
<td>2</td>
<td>14</td>
<td>16</td>
</tr>
<tr>
<td>3</td>
<td>14.8</td>
<td>26.3</td>
<td>34</td>
<td>2</td>
<td>16</td>
<td>18</td>
</tr>
</tbody>
</table>

* Used in regression models along with DBH.
Acknowledgments

The computing assistance given by Shan Wu Jan, at the time a Research Assistant in the School of Forestry and Conservation, is gratefully acknowledged. Computer time for this study was made available by the University of California Computer Center.

LITERATURE CITED

BELL, J. F. and W. A. GROMAN

BRUCE, D. and F. X. SCHUMACHER

DRAPER, N. R. and H. SMITH

GROSENBAUGH, L. R.

MEYER, H. A.

NAUS, J. I.
The journal HILGARDIA is published at irregular intervals, in volumes of about 650 to 700 pages. The number of issues per volume varies.

Single copies of any issue may be obtained free, as long as the supply lasts; please request by volume and issue number from:

Agricultural Publications
University of California
Berkeley, California  94720

The limit to nonresidents of California is 10 separate titles. The limit to California residents is 20 separate titles.

The journal will be sent regularly to libraries, schools, or institutions in one of the following ways:

1. In exchange for similar published material on research.
2. As a gift to qualified repository libraries only.
3. On a subscription basis—$7.50 a year paid in advance. All subscriptions will be started with the first number issued during a calendar year. Subscribers starting during any given year will be sent back numbers to the first of that year and will be billed for the ensuing year the following January. Make checks or money orders payable to The Regents of The University of California; send payment with order to Agricultural Publications at above address.