Honors Research Project File

ESTIMATING OAK TREE VOLUME FROM STUMP DIAMETER IN SOUTHEASTERN OHIO

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Abstract

When a tree has been cut down and only the stump remains, an equation may be made to predict the tree's volume from its stump diameter. Several measurements, both on the tree itself and on the environment have been taken to determine this model for oaks in southeastern Ohio.

SUMMARY

The all variable equations for each species proved to have very high correlation coefficients. The stump diameter equations had somewhat poorer correlation coefficients but the stump diameter equations at 18 inches above the ground may still be acceptable.

The equations for volume estimation are one of the few sets anywhere to use environmental variables as predictors. These variables increased the multiple correlation coefficients for each species.

These equations will provide consulting foresters, timber owners, and others involved in forestry the ability to predict the volume of oak trees which have been cut. The statistical methodology used in developing these equations and their associated R-squared coefficients permit the user to assess the reliability of volume prediction.

INTRODUCTION

Determination of tree volume from stump measurements is important to foresters for several reasons. Such volume determination will give foresters the ability to (1) calculate growth on cut as part of a forest inventory, (2) predict removals from a large forest area, (3) and most important, give them the ability to estimate losses in timber trespassing cases.

Timber trespassing has been a problem in Ohio for many years. Lumbermen either accidently or intentionally remove trees from property outside the timber sale boundaries. Estimates of these losses are difficult to determine since the stump is the only remaining portion of the tree.

Very little research has been done on the relationship between stump diameter and tree volume. Most of the research involving stump diameter has dealt with its relationship to diameter at breast height (dbh) a standard forest volume prediction measurement. The relationship of stump diameter to tree volume research has not been published for Ohio.

The objective of the research was to determine the regression relationship between oak tree volumes and stump diameter for the southeast forest region of the State of Ohio.

Data collection was limited to oak trees of at least sawtimber size (11.0 inches diameter or larger at d.b.h.). Oak trees were chosen as the group to be measured because they have the greatest total value of any tree group in Ohio.

Southeastern Ohio, namely Hocking, Vinton, and Athens counties was used as the data collection site for four reasons:

1) It has the highest percentage of forested lands of any section in Ohio;

2) It has easily accessible public forested lands;

3) This area has the largest percentage of oak trees on the land which is forested;

4) It has a diversity of site conditions that provided a wide range of data.

The remaining sections of the paper describe the methods and procedures which were implemented, and the results of the project.

LITERATURE REVIEW

Literature on the direct relationship between stump diameter and tree volume is difficult to find. As was stated before, most research involving stump diameter deals with its relationship to d.b.h. Volume tables are then used to predict the tree's volume from its corresponding d.b.h.

Diameter breast height has been predicted from stump diameters in several ways. Graphs and charts were used to predict d.b.h. from stump diameters in earlier studies such as Rapraeger (1941), and Endicott (1959). Tables or "rules of thumb" were used by McCormack (1953), and Horn and Keller (1957) in predicting d.b.h. from stump diameter. Regression techniques have also been used in predicting d.b.h. and tree volume from stump diameter. Studies which have utilized this method of analysis are Myers (1963), McClure (1968), and Nyland (1977). In a research paper by Carl Bylin (Aug. 1982) entitled "Volume Prediction from Stump Diameter and Stump Height of Selected Species in Louisiana", he states that the regression technique is the best method to use in predicting tree volume from stump diameter.

Aside from the differences in data analysis, differences exist as to what stump measurements are used in predicting d.b.h. and tree volumes.

In research done by Ralph Nyland (1977) on the relationship between d.b.h., stump diameter and stump height, he found that by adding the stump height measurement, estimates of d.b.h. improved significantly.

On the other hand Clifford Myers (1963) in his research on estimating volumes and d.b.h. from stump diameters used the stump diameter measurement singly in predicting d.b.h.

Carl Bylin (Dec. 1982) in a research note entitled "Estimating d.b.h. from Stump Diameter for 15 Southern Species" also used stump diameter as the single measurement in predicting d.b.h. In an earlier research paper on volume prediction from stump diameter (Aug. 1982), he reported that the inclusion of stump height improves slightly but not significantly the volume prediction equation's multiple correlation coefficient.

Two different measurements may be taken to determine stump diameter. Stump diameter inside bark has been used as a measurement of stump diameter, (Nyland, 1977). Stump diameter outside bark has also been used as the measurement for stump diameter, (McClure, 1968).

In Carl Bylin's Research Note on estimating d.b.h. from stump diameter he states "equations predicting d.b.h. from stump diameter outside bark were slightly more accurate than those equations using stump diameter inside bark".

Differences in stump diameter measurements used in an equation become very important. Without conceding effectiveness, the equation should be as simple as possible. The simpler the equation is to use, the easier and less time consuming it will be as a tool in prediction of d.b.h. or tree volume.

METHODS AND PROCEDURES

Data Collection

Data was collected on nine variables which I thought would significantly affect the volume-stump diameter relationship.

The environmental variables that I measured were aspect, basal area, slope position, and site index. Aspect was included as a variable in the study because of its possible affect on the tree's growth form. Aspect is the direction a slope faces. Different aspects receive differing amounts of sunlight. Thus, tree growth and growth form may be affected.

The basal area variable was used as a measure of density around the tree. Density of the forest had a large affect on growth and may also affect the growth form of a tree. The denser the area around the tree, the less nutrients, sunlight, and water the tree receives. Thus, the growth of a tree in a very dense area is less than optimal.

The position a tree occupies on a slope also affects growth and may affect growth form. Ridgetops have less top soil and are usually better drained than bottom lands. Certain species of trees seem to grow better in the rich soil located in bottom land areas. But these areas usually have poorer drainage which may inhibit tree growth. The side slopes are somewhere in between in terms of drainage and nutrient content.

Site index may affect tree growth. Site index is a measure of the quality of the site the tree is growing on It is determined by making direct measurements on the tree itself.

All these environmental variables were chosen to be measured because of their affect on tree growth and their possible affect on the tree's growth form.

Stump diameters were the non-environmental variables included in the study. The diameter was the most important variable measured because of its close correlation with tree volume. Diameter breast height and number of logs in each tree were also measured. Using the Doyle Rule Form Class 78 the volume was determined.

Data collection took place in the summer of 1984. Information gathered on each tree included species and a series of measurements which were taken on the tree.

A diameter tape was used to measure stump diameter at 6 inches, 12 inches, and 18 inches above the root collar. A Merrit hypsometer was then used to measure the number of logs in the tree. The grade of the butt log was also estimated.

Following completion of tree measurements, several environmental factors were measured. Site index was the first factor to be determined. This measurement involved taking an increment core from the tree to determine the age of the tree. Then using an abney level, the tree's total height was determined. These two data points were interpreted on a height over age set of site index curves.

Aspect was the next factor. A compass was used to determine the azimuth of the slope on which the tree was growing.

The position the tree occupied on the slope (top, middle, or bottom) was also determined. The ridge top was defined as the top and one eighth down each side of the hill. The bottom was defined as bottom and one eighth up each side of the hill. The side hill was defined as the middle 75 % of the hill between ridge top and bottom.

The last factor to be determined was the basal area per acre. Using a 10-factor prism, the basal area was determined within a circular plot with the tree as the center.

<u>Data Analysis</u>

Data analysis was performed using multiple stepwise linear regression on the statistical analysis system (SAS) contained on the computer system at The Ohio State University center.

The actual procedure I used was the maximum R-squared improvement technique developed by James H. Goodnight.

When using this method, the computer found the variable that gave the highest R-squared value. The R-squared value measures how much variation in the dependent variable (in this case tree volume) can be accounted for by the model. In general the larger the value of R-squared the better the model fits. Then the next variable that increased the R-squared value the most was added to the model.

After this two variable model was found, each variable in the model was compared to each variable not in the model. The computer determined if taking out one variable and replacing it with another variable yielded a higher R-squared value. The one which yielded the highest R-squared value was printed. The two-variable model the computer derived had the highest possible R-squared value for the entire list of independent variables. This process continued until all independent variables had been entered into the model.

The best model was the simplest equation in which all the variables were significant, and the addition of the next variable did not significantly increase the value of R-squared.

Simple linear regression was also performed on the data using the stump diameters at various heights above the ground as single predictors of volume.

RESULTS

The results of the multiple stepwise regression procedure are located in Table 1.

Each species has its own volume predicting equation along with it's corresponding R-squared coefficient.

An equation was also produced that can be used to predict volume regardless of the species of the tree being measured.

Tables 2,3, and 4 show the results of simple linear regression with single diameter measurements used as predictor variables. Table 2 includes stump diameter measurements at 18 inches above the ground. Table 3 includes stump diameter measurements at 12 inches above the ground and table 4 includes stump diameter measurements at six inches above the ground. These tables also include the R-squared coefficients and the range of stump diameters which were measured. Figures 1,2,3 show line equations for stump heights of 18, 12, and 6 inches, respectively.

A sizeable decrease is seen in R-squared coefficients when using the single stump diameter measurements as predictors of volume. In contrast when using the equation in table 1 in which several variables are included, the R-squared coefficients are much higher.

An F-test was performed on each of the three forced stump diameter equations to compare the individual species equations with the equation that included all species. This comparison was made to determine if the all species equation could be substituted for each of the different species equations when predicting tree volume.

All three tests were rejected. The all species equation cannot be substituted for each of the species equations. The results of the three F-tests are located in Appendix A.

Diameter squared was also tested as a possible predictor of volume. This measurement did not significantly increase the R-squared coefficients of the equations.

DISCUSSION

Use of the equations is dependent on the situation and measurements which are available. If specific species can be determined, the individual species equation should be used in volume prediction. These equations are more accurate then the all species equation. In all five species equations the diameter of the trunk 18 inches above the ground is included as a variable. In many cases this measurement might not be available. The equation which would then be used is the equation with the diameter measurement at 12 inches above the ground. This equation has the next best correlation coefficient.

The equations with single diameter measurements are quicker to use in the field, but they are less accurate than the equations with several variables. If a rough estimate of volume is the goal of the user, then the single diameter equations may be adequate. However, if accuracy is the objective then the species equations with several variables should be used.

In general, the use of the equations will be determined by the accuracy of the volume needed and the variables available for measurement.

These equations can be used on the five species of oaks for the southeastern part of the State of Ohio. Use of these equations outside this area or on different species of oaks may lead to erroneous results.

The equations will be useful in any situation in which the volume of the oak tree is unknown and it's stump is left to be measured.

For example, Farmer Brown owns 35 acres of prime white oak. He discovers 10 of these trees have been felled and hauled away. The only remaining part of the tree is the stump. The trees are insured but Farmer Brown has no idea of their worth.

In a case such as this the equations which I have developed would be very useful. If Farmer Brown contacted me about his problem, I would have him use the white oak equation. By making the necessary measurements he could determine the board foot volume. The dollar value of the trees could be determined using current market prices. The dollar amount determined would not be an exact value, but rather a single estimate in a range of possible values. The size of this range would be determined by the R-squared coefficient. The closer the R-squared coefficient is to 1.0 the smaller the range.

CONCLUSION

The equations contained in this report provide a statistically sound method of determining oak-tree volumes from stump diameter and other environmental variables. A great deal of research has been done on the estimation of d.b.h. from stump diameter. The d.b.h. value is then used to predict volume. This two-step method introduces two sources of error. Estimating d.b.h. from stump diameter is the first source of error. The second source of error occurs when d.b.h. is used to determine tree volume. When using the equations which I have developed, volume is predicted directly from stump diameter and other measurements. Thus, only one source of error or variability is introduced. The R-squared coefficient is used as a gauge to determine the amount of variability which may occur.

For this reason, the direct estimation alternative is a more statistically sound method of determining tree volume from stump diameter. Though effective use of these equations is limited to oaks in southeastern Ohio, hopefully, equations can be developed for other species and in other areas using this direct estimation method.

TABLE 1

All Variables	n	R^2
Black Oak		
Vol = -778.85 + Eig * 36.61 + SI*89.42	25	.85
Chestnut Oak		
Vol = -510.23 + Eig*36.6 + Slo*1.0 + Asp*-61.3	15	.96
Red Oak		
Vol = -1238.67 + Eig*44.2 + Age*4.62 + Ba*16.88	26	.96
Scarlet Oak		
Vol = -1425.89 + Eig*65.44 + Asp*118.64	23	.94
White Oak		
Vol = -514.70 + Twe*13.34 + Eig*13.33 + SI*36.24 + Slo * .062	25	.92

Vol = volume of tree in board feet

Eig = stump diameter (inches) at eighteen inches above the ground

SI = site index at age 50

Slo = position tree occupies on slope 1 = ridgetop
2 = side slope 3 = bottom

Asp = Aspect of area tree is located on NE = 1 SE = 2
SW = 3 NW = 4

Age = age of tree in years

Ba = basal area per acre (square feet)

Twe = stump diameter (inches) at twelve inches above the ground

Table 2

Diameter equations at 18 inches above ground

Species	b_0	b_1	n	R^2	stump diam. range (in.)
Black Oak	-639.55	40.40	25	.71	14.5-33.0
Chestnut Oak	-547.09	37.1	15	.92	15.0-24.9
Red Oak	-721.95	45.07	26	.87	14.2-38.0
Scarlet Oak	-1144.60	63.85	23	.94	18.2-36.6
White Oak	-601.87	38.6	25	.79	14.1-38.0
All	-755.00	46.75	114	.85	14.1-38.0

vol = b_0 + b_1 * stump diameter

Table 3

Diameter equations at 12 inches above the ground

Species	b_0	b_1	n	R^2	Stump diam. range (in.)
Black Oak	-478.56	32.29	25	.53	15.0-35.7
Chestnut Oak	-495.38	32.45	15	.91	15.7-26.5
Red Oak	-495.38	34.26	26	.62	15.9-41.0
Scarlet Oak	-1140.44	60.4	23	.92	19.2-38.0
White Oak	-534.15	33.69	25	.83	14.9-27.1
All	-639.75	39.36	114	.74	14.9-41.0

Vol = b_0 + b_1 * stump diameter

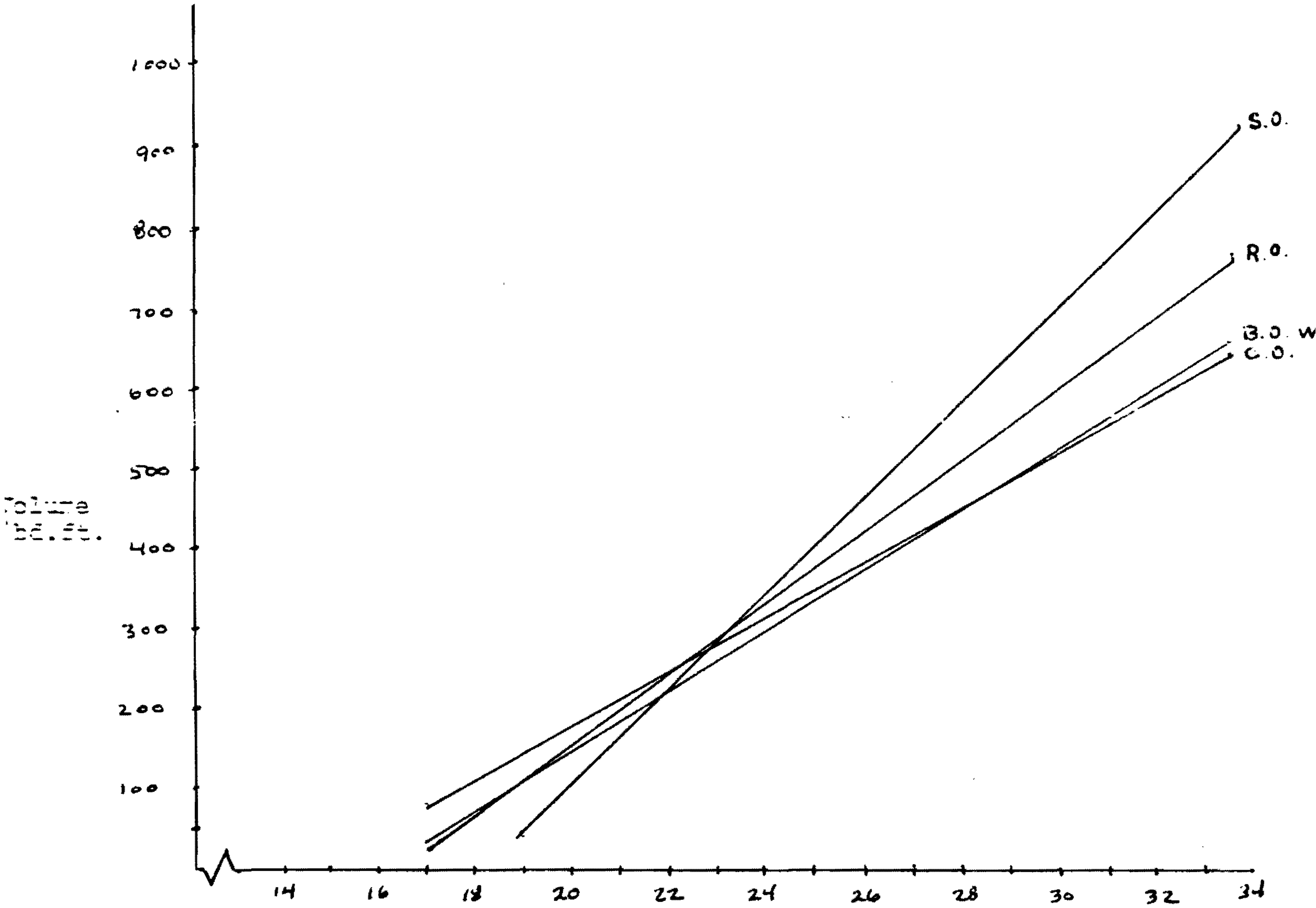
Table 4

Diameter Equations at 6 inches above the ground

Species	b_0	b_1	n	R^2	stump diam. range (in.)
Black Oak	-446.92	28.1	25	.51	15.8-39.6
Chestnut Oak	-485.66	29.79	15	.92	16.8-29.4
Red Oak	-590.74	32.91	26	.76	15.1-46.0
Scarlet Oak	-1068.84	52.81	23	.89	21.0-41.0
White Oak	-548.60	31.23	25	.75	16.0-29.9
All	-629.95	35.48	114	.75	15.1-46.0

$Vol = b_0 + b_1 * \text{stump diameter}$

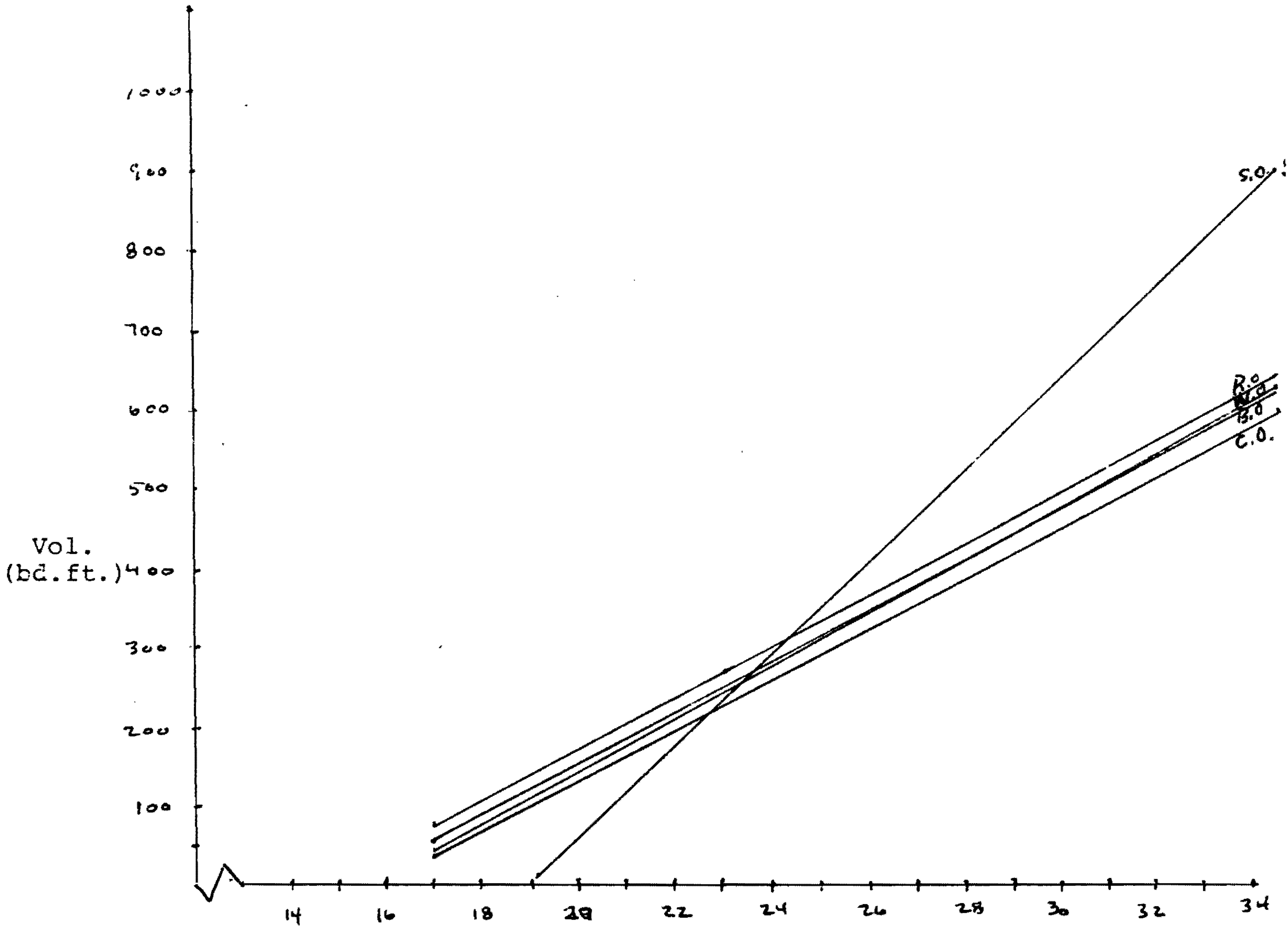
Figure 1. Graph of Stump Diameter Equation at 18 inches above the root collar



STUMP DIAMETER
(inches)

B.O. = Black Oak
W.O. = White Oak
R.O. = Red Oak
S.O. = Scarlet Oak
C.O. = Chestnut Oak

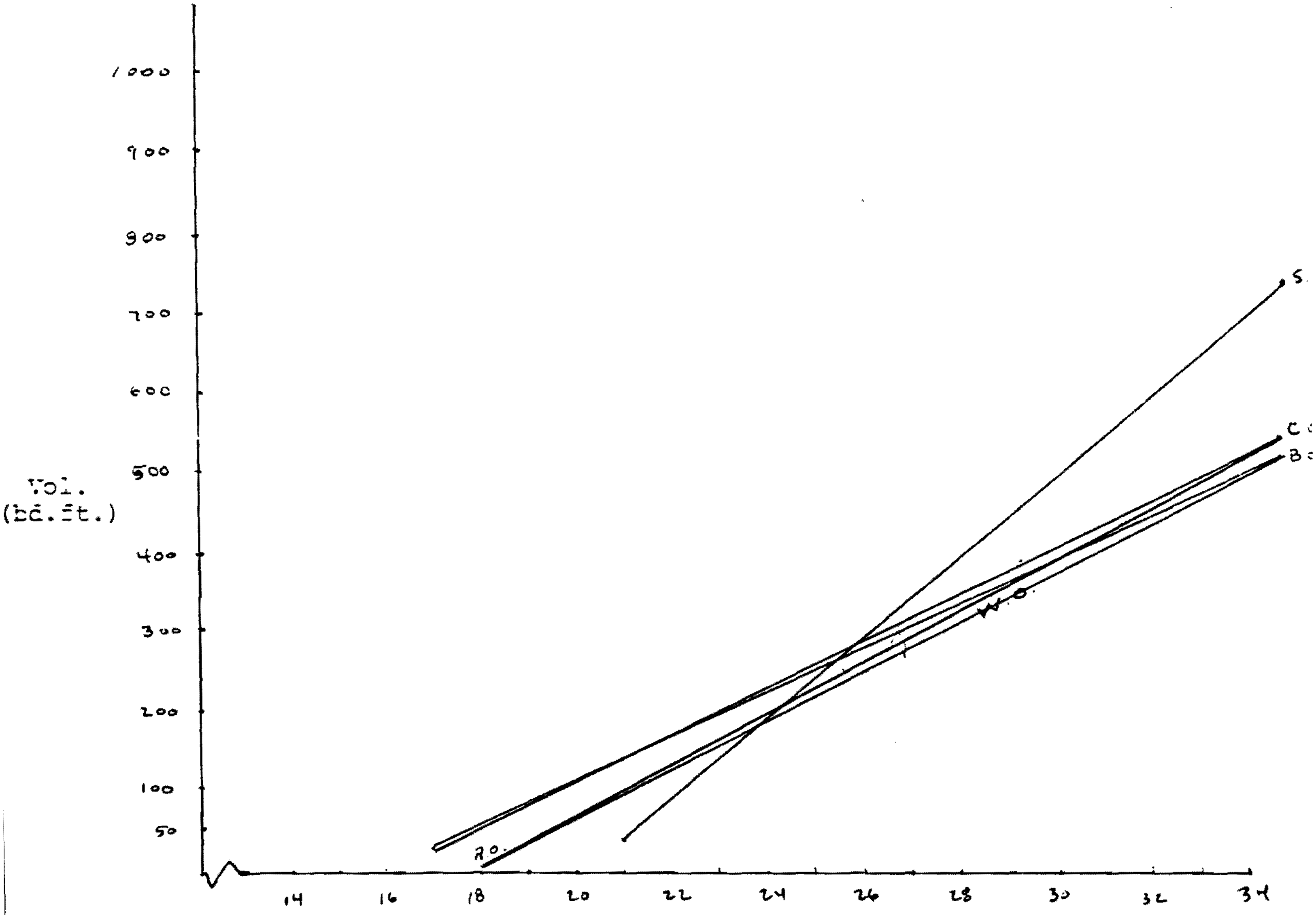
Figure 2. Graph of Stump Diameter Equation at 12 inches above the root collar



STUMP DIAMETER (inches)

B.O. = Black Oak
W. O. = White Oak
C.O. = Chestnut Oak
R.O. = Red Oak
S.O. = Scarlet Oak

Figure 3. Graph of Stump Diameter Equation at six inches above the root collar



STUMP DIAMETER
(inches)

S.O. = Scarlet Oak
W.O. = White Oak
R.O. = Red Oak
C.O. = Chestnut Oak
B.O. = Black Oak

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APPENDIX A

$$F = \frac{\frac{SSt - SSp}{(m + 1)(k - 1)}}{\frac{SSp}{DFp}}$$

Eighteen

$$F = \frac{\frac{980428.59 - 742572.3}{(2)(4)}}{\frac{742572.38}{102}} = 4.08$$

Twelve

$$F = \frac{\frac{1752156.24 - 1398598.8}{(2)(4)}}{\frac{1398598.8}{102}} = 3.22$$

Six

$$F = \frac{\frac{1623410.40 - 1276865}{(2)(4)}}{\frac{1276865}{102}} = 3.46$$

If $F > F_{.05}$ reject Ho

$F_{.05} = 2.17$