COMPONENT DRY WEIGHTS OF 100-YEAR-OLD LODGEPOLE PINE TREES

by

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INTRODUCTION

Forest mensurationists have expended much effort in the development of formulas and tables for estimation of the growing crop in cubic or board feet, or in cords. Although there is still some doubt about which form of equation is best, the demand for methods of obtaining reliable estimates of tree volume has been mostly satisfied. However, there is also a need for methods of estimating biomass, which is the total quantity of organic matter, usually expressed in dry weight, present in a forest stand at a given time.

The measurement of forest biomass dates back to the work of Burger (1929), and Mar:Moller (1947). Much information on forest biomass has been gathered by the Japanese over the last decade (Tadaki, 1966; Kira and Shidei, 1967). Interest on this continent has grown with the work of Young <u>et al</u>. (1964) and Baskerville (1965a).

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A uniform methodology has not been established for the measurement of biomass in forest trees and stands. Little attention has been given to the suitability or reliability of the methods used. Measuring all of the trees present in an area is impractical because of the technical problems of handling and weighing the trees. Consequently, sampling is the only suitable alternative. A biomass study of lodgepole pine was initiated in 1966 and this paper presents some of the relationships which exist among the dry weights of several tree-components and several easily measured tree characteristics.

METHODS

Data Collection

The data used in this study were collected on the Kananaskis Forest Research Station (North Latitude 52°, West Longitude 115°) in the SA 1 Section of the Subalpine Forest Region (Rowe, 1959).

The study area was on a well-drained, gently sloping site at an elevation of about 4,600 feet. The soil was an aeolian loamy silt interbanded with alluvial materials that had a fine matrix. The soil profile was weakly developed and was highly calcareous to within 8 inches of the surface.

Two square, tenth-acre plots were located in stands that were predominantly lodgepole pine, with some western white spruce (*Picea glauca* (Moench) Voss var. *albertiana* (S. Brown) Sarg.) in the understory. The pine trees were all about 100 years old.

The first study plot (felled and measured in 1966) was located in an undisturbed stand and the second (felled and measured in 1967) was established in a stand that had been thinned in 1938. The thinning treatment was a "French" or crown thinning. Table 1 presents the stand characteristics immediately before and after thinning in 1938, and when measured for this study in 1966 and 1967.

Table 1. Characteristics of the thinned and unthinned lodgepole pine plots.

	Thinned Plot				Unthinned Plot			
	No. Stems/ acre	B.A./acre (sq. ft.)	Vol./acre (cu. ft.)	$\bar{D}$ (in.)	No. Stems/ acre	B.A./acre (sq. ft.)	Vol./acre (cu. ft.)	$\bar{D}$ (in.)
Before Thinning (1938)	2,003	187.6	4,149	3.6	3,005	195.6	3,905	3.5
After Thinning (1938)	1,220	128.6	2,910	4.4		(unchanged)		
At Study Time (1966) (1967)	290	152.0	5,107	9.8	1,020	227.7	6,356	6.4

Diameter at breast height, average crown width (the average of two measurements taken at right angles at the widest part of the crown), total tree height, and live crown length (the length from the tip to the lowest whorl of live branches) were measured.

The trees were then cut at 1 foot above the ground. A dial scale with a capacity of 500 pounds was used to weigh the trees. The first weight obtained was that of the entire tree above stump height (including branches and foliage). The entire stem (the total tree less branches and foliage) was weighed and then the merchantable stem weight to a 4.0-inch top diameter outside bark was obtained.

Bole and bark

Discs, each about one inch thick, were sawn from the stem at stump height, breast height, and at eight-foot intervals above stump height. The diameter outside bark of each disc was measured and recorded on a stem-analysis sheet. The discs were placed in sealed polyethylene bags for transport to the laboratory.

In the laboratory, the bark was separated from each disc and the diameter inside bark of each disc was measured. The wood and bark of each disc were weighed separately and placed in a drying oven for 24 hours at a temperature of 105°C. Repeated tests showed that 24 hours was sufficient time for the discs to reach a constant oven-dry weight. Upon completion of the drying period, the discs and bark were removed from the drying oven and reweighed. The moisture contents of the bark and wood of each disc were determined.

Because moisture content within a tree was found to increase from the base to the top of a tree, an arithmetic average moisture content was not deemed representative. Therefore, the average moisture content for the entire tree was determined by weighting the average moisture content of two consecutive discs by the volume (calculated by Smalian's formula) of the section between the two discs. A similar method was used to calculate a weighted average bark moisture content. Fresh volume, inside and outside bark, was determined from Reineke charts and the specific gravity of bark (Smith and Kozak, 1967) was multiplied by bark volume to estimate bark dry-weight.

Branches and foliage

After the entire tree above stump height was weighed the foliage-bearing twigs were clipped from the larger branch parts, put into burlap sacks, and weighed. The bags were placed in a drying shed in which the temperature was maintained at about 85°C. Repeated tests revealed that a two-week drying period at 85°C was required to ensure that the foliage had reached a constant oven-dry moisture content. The dried needles were removed from the twigs by hand and the cleaned needles (without fascicles) were weighed.

Needle moisture-content data (Kiil, 1968) were used to estimate the fresh needle weight of each tree. The weight of fresh branches for each tree was obtained by subtracting the estimated weight of fresh needles from the measured fresh weight of crown materials (needles plus branches). The dry branch weight per tree was then estimated by reducing the calculated fresh branch weight by the moisture content of branch wood (Kiil, 1968).

Roots and stumps

In the spring of 1968, a D-8 Caterpillar tractor was used to uproot the stump-root components. The roots were washed free of soil particles and weighed after the surface had dried. Discs were cut from the root and stump components so that dry-weight calculations could be made. Although some root materials were lost in this method of extraction, the losses were small.

Analysis

Because the thinning had no apparent affect on the weight or distribution of the trees' components, the data from the two sample plots were pooled. The data from 85 trees were analyzed by multiple regression techniques, with the computer program described by Kozak and Smith (1965). Tree component dry-weights, in pounds, were used as dependent variables with the tree characteristics presented in Table 2 as independent variables.

The following were used as dependent variables in the regression analyses of the tree and component weights (lb):

a) Total Tree Weight (Y_1) - The dry weight of all components including needles, branches, cones, bole wood, bark, and the root-stump component.

b) Total Above-ground Weight (Y_2) - The dry weight of all components above a 1-foot stump.

c) Total Stem Weight (Y_3) - The total tree dry-weight above a 1-foot stump less the dry weight of branches, needles, and cones.

d) Stem Bark Weight (Y_4) - The dry weight of stem bark above a 1-foot stump.

e) Needle Weight (Y_5) - The dry weight of needles.

f) Branch Weight (Y_6) - The dry weight of branches.

g) Stump plus Root Weight (Y_7) - The dry weight of a 1-foot stump plus roots.

h) Root Weight (Y_8) - The dry weight of that portion of the tree below ground level.

The regression equations presented in the following section for tree and tree component weights are of a logarithmic transformation form. Logarithmic transformations were used to facilitate the application of a linear model and permit comparisons with similar work presented in the literature which most frequently uses this transformation.

In the following results the standard error of estimate is expressed both in absolute units and as a percentage of the mean, the latter being in parentheses. Because the standard error of estimate determined from the residual mean square of a logarithmic equation cannot be transformed back to an arithmetic scale, the standard errors of estimate were calculated by the following formula:

$$SE_E = \pm \sqrt{\frac{(Y - Yest.)^2}{n-2}}$$

RESULTS

Table 2 presents the means, standard deviations, and maximum and minimum values of the independent variables used in the analyses.

Table 2. Statistical characteristics of the independent variables from 85 lodgepole pine trees.

Independent Variable	Mean	Standard Deviation	Minimum Value	Maximum Value
Diameter (D) (in.)	7.1	2.1	4.0	13.4
Height (H) (ft.)	60.4	7.5	45.0	81.7
Crown Length (CL) (ft.)	21.6	10.3	8.0	54.0
Crown Width (CW) (ft.)	53.6	2.0	2.5	14.7
Age (AGE) (yrs.)	92.4	4.9	75.0	100.0
Height to Live Crown (Ht.LC) (ft.)	38.8	6.6	20.1	50.8
Tree Basal Area (BA) (sq.ft.)	0.3	0.2	0.1	1.0
Diameter Squared times Height (D^2H) ($in.^2.ft.$)	3,498.4	2,581.0	760.0	13,792.3

The means, standard deviations, and minimum and maximum values of the dependent variables are presented in Table 3.

Table 3. Statistical characteristics of the dependent variables from 85 lodgepole pine trees.

Dependent Variable	Mean	Standard Deviation	Minimum Value	Maximum Value
Dry Total Tree Weight (Y_1) (lb.)	372.7	280.1	92.3	1,530.3
Dry Above Ground Weight (Y_2) (lb.)	311.4	226.2	64.4	1,238.1
Dry Stem Weight (Y_3) (lb.)	268.9	179.8	58.9	944.3
Dry Bark Weight (Y_4) (lb.)	31.2	29.7	5.4	170.8
Dry Needle Weight (Y_5) (lb.)	14.0	11.7	1.0	61.2
Dry Branch Weight (Y_6) (lb.)	21.8	30.8	0.5	194.9
Dry Root plus Stump Weight (Y_7) (lb.)	57.4	49.8	13.2	292.2
Dry Root Weight (Y_8) (lb.)	51.5	48.1	9.1	283.5

Simple correlation coefficients (r) between the transformed dependent and independent variables are shown in Table 4. The combined variable $Log_{10}\ D^2H$ is most closely associated with tree component weights. Tree basal area or diameter was the second most important variable for estimating the various component weights. Because of the nature of the transformation, tree basal area and diameter had identical correlation coefficients with the various dependent variables. Age and height-to-live-crown are poorly correlated with tree and component weights.

Table 4. Simple correlation coefficients between tree and component weights and some tree characteristics for 85 lodgepole pine trees.

Dependent Variables (Log_{10})	Independent Variables (Log_{10})						
	DBH (BA)	Ht.	CL	CW	AGE	Ht. LC	D^2H
Dry Total Tree Weight (Y_1)	0.991**	0.947**	0.770**	0.858**	0.227^{ns}	-0.138^{ns}	0.993**
Dry Above Ground Weight (Y_2)	0.989**	0.951**	0.767**	0.848**	0.297**	-0.114^{ns}	0.992**
Dry Stem Weight (Y_3)	0.986**	0.953**	0.760**	0.833**	0.296**	-0.101^{ns}	0.989**
Dry Bark Weight (Y_4)	0.917**	0.912**	0.812**	0.764**	0.224*	-0.235*	0.925**
Dry Needle Weight (Y_5)	0.920**	0.880**	0.753**	0.840**	0.421**	-0.156^{ns}	0.922**
Dry Branch Weight (Y_6)	0.895**	0.842**	0.700**	0.840**	0.297**	-0.153^{ns}	0.895**
Dry Root plus Stump Weight (Y_7)	0.972**	0.926**	0.757**	0.863**	0.198^{ns}	-0.143^{ns}	0.974**
Dry Root Weight (Y_8)	0.969**	0.921**	0.757**	0.863**	0.203^{ns}	-0.148^{ns}	0.971**

** significant at the 0.01 probability level
* significant at the 0.05 probability level
n.s. not significant at the 0.05 probability level

(Note: These notations will be used, as defined above, throughout this paper.)

Figures 1 to 8 show the best regression equations developed by the analysis. $\mathrm{Log}_{10}\ D^2H$ was the best independent variable for estimating the component weights. Always, $\log_{10}$ diameter ($\log_{10}$ tree basal area) was second only to $\log_{10}\ D^2H$ for prediction reliability.

Of the eight dependent variables analyzed, only four (dry stem weight, dry needle weight, dry stump weight, and dry root weight) were obtained by direct measurement. The remaining four dependent variables (dry total tree weight, dry total above ground weight, dry bark weight, and dry branch weight) were determined indirectly and, consequently, it is very likely that their variability was reduced somewhat. Therefore, it is probable that the standard errors of estimate, and the spread between the maximum and minimum values of these variables, are low.

DISCUSSION

It is possible to make highly reliable estimates of the dry weights of the various components of lodgepole pine from relatively simple measurements of tree height and diameter. Because of the inherent errors discussed previously, estimates could be further improved if direct measurements were used to determine the quantity of bark and branch materials.

The results suggest double sampling with regression will give reliable and easily obtained estimates. This study supports the contention of Baskerville (1965b), and Kira and Shidei (1967) that estimates based on double regression are superior to those obtained by the stock estimation (average tree) method.

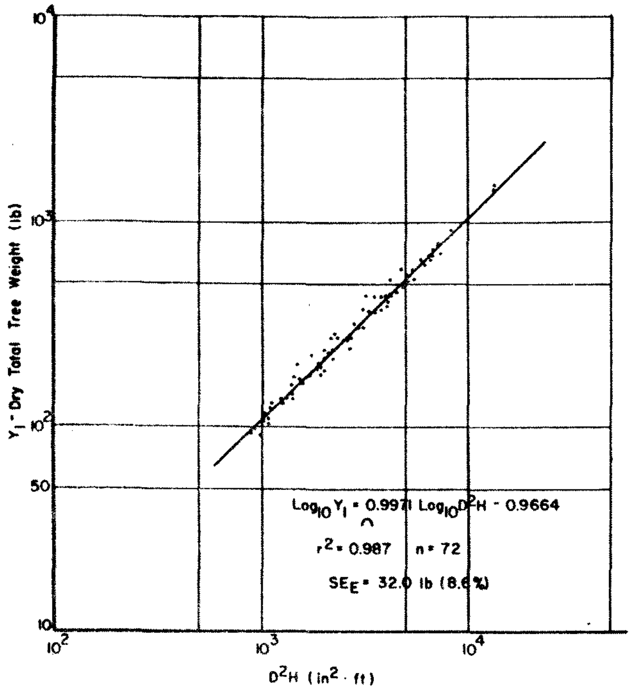

Figure 1. TOTAL TREE WEIGHT-D^2H ALLOMETRY OF 100-YEAR-OLD LODGEPOLE PINE.

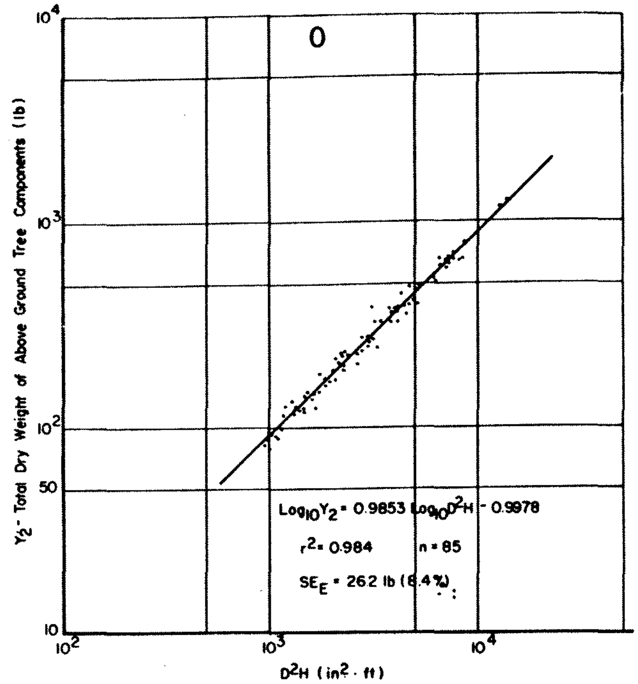

Figure 2. TOTAL ABOVE GROUND COMPONENT WEIGHT-D^2H ALLOMETRY OF 100-YEAR-OLD LODGEPOLE PINE

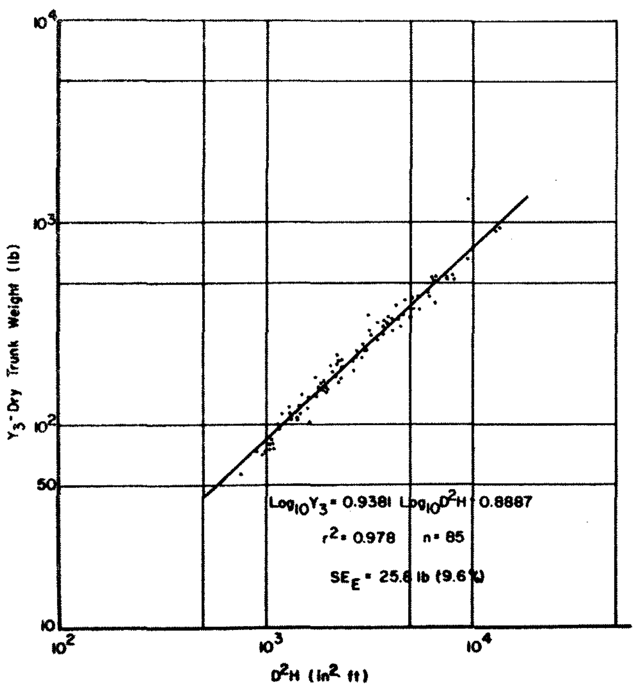

Figure 3. TRUNK WEIGHT-D^2H ALLOMETRY FOR 100-YEAR-OLD LODGEPOLE PINE.

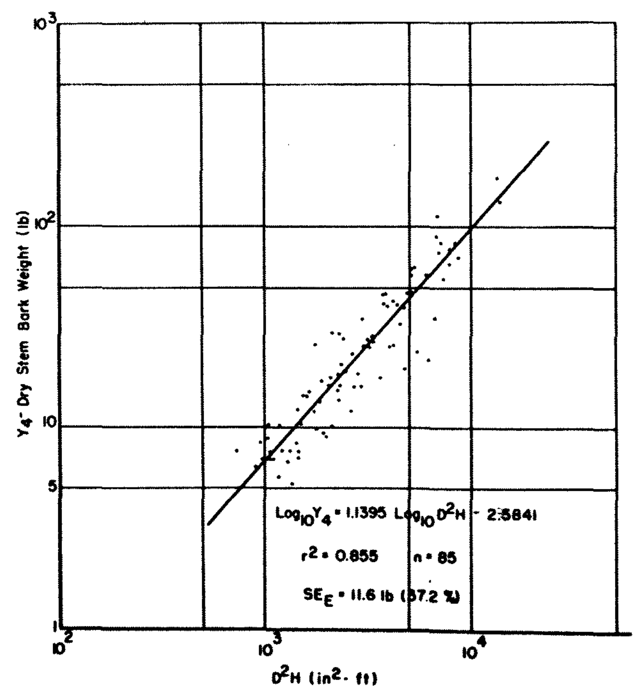

Figure 4. STEM BARK WEIGHT-D^2H ALLOMETRY OF 100-YEAR-OLD LODGEPOLE PINE.

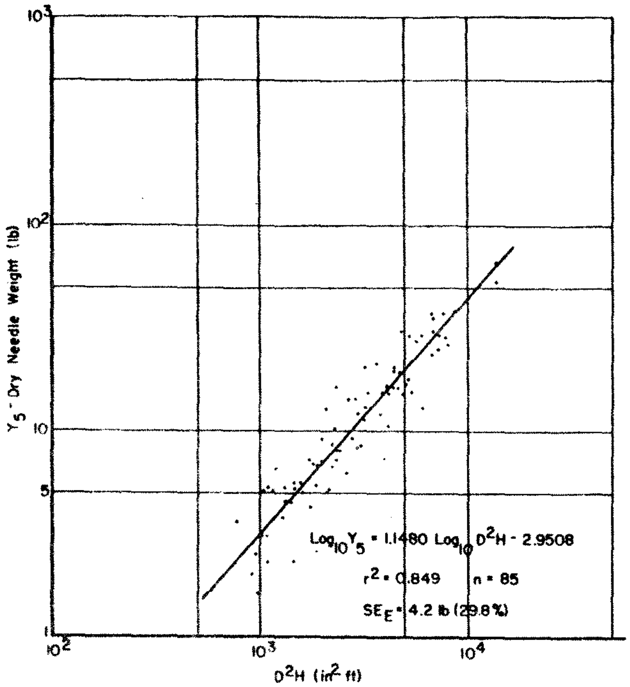

Figure 5. NEEDLE WEIGHT D^2H ALLOMETRY OF 100-YEAR-OLD LODGEPOLE PINE.

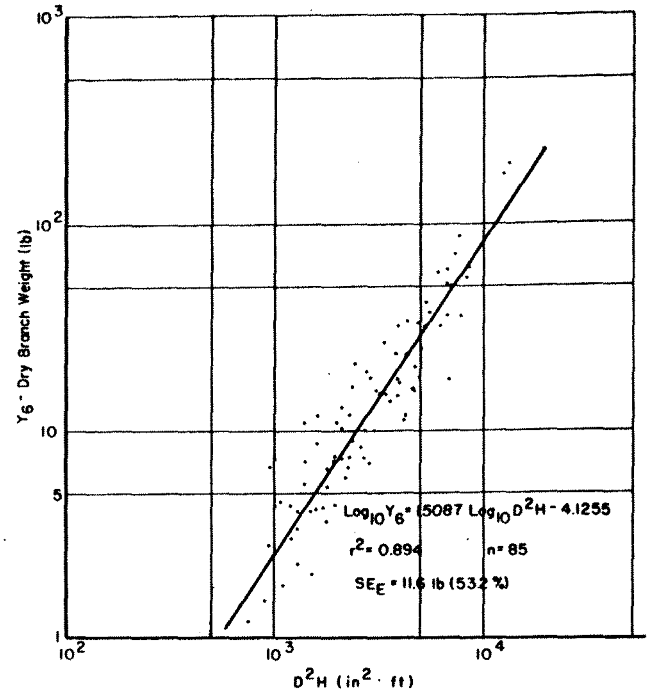

Figure 6. BRANCH WEIGHT - D^2H ALLOMETRY FOR 100-YEAR-OLD LODGEPOLE PINE.

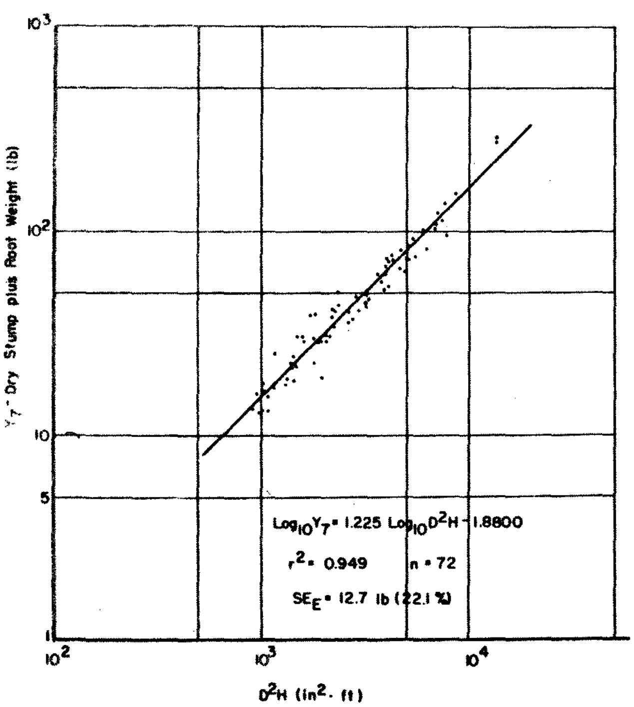

Figure 7. STUMP PLUS ROOT WEIGHT-D^2H ALLOMETRY FOR 100-YEAR-OLD LODGEPOLE PINE.

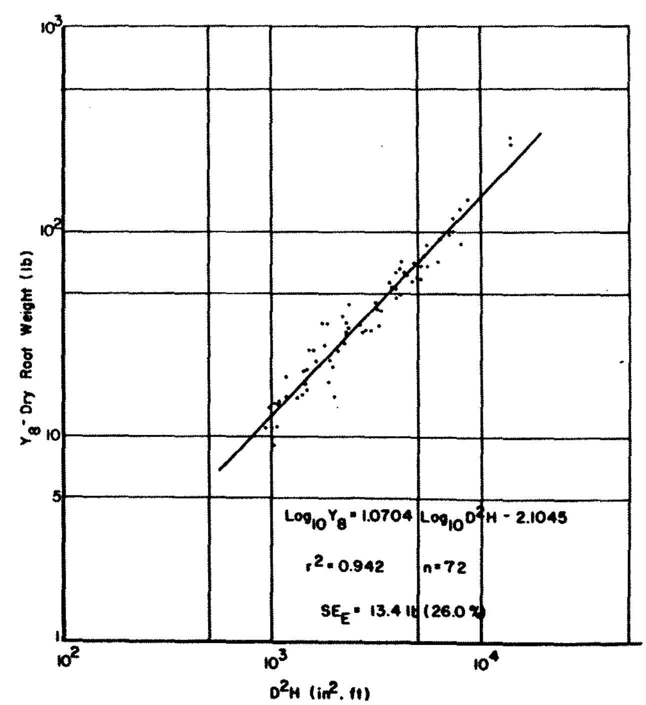

Figure 8. ROOT WEIGHT - D^2H ALLOMETRY FOR 100-YEAR-OLD LODGEPOLE PINE.

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