STEM VOLUME ESTIMATION IN YOUNG
COTTONWOOD CLONES -- WHICH EQUATION?

Ronald A. Woessner[1/]

Abstract.--Stem form characteristics were studied in nine cottonwood clones and a nursery run lot. Form quotient differences outside bark among the clones were closely related to clonal bark thickness differences. Ten individual simple linear regression equations for predicting total cubic-foot stem volume outside bark from total height and diameter at breast height were derived. A pooled equation combining all the data was also derived. Statistical tests indicated that the regressions and the intercepts were not equal and thus the data should not be combined.

However, cubic foot volumes were estimated for each of the clones using the pooled equation and an equation previously published. Both of these equations predicted volume accurately enough in this study to allow a true ranking of the clonal lines for stem volume. Conversely, an accurate estimate of actual wood volume production of an individual clone in response to a treatment will most likely require individual clonal equations derived from inside bark data.

Additional keywords: Linear regression, Populus deltoides.

Volume is frequently chosen, rather than height or diameter as a more meaningful way to evaluate tree growth. This is logical if a volume equation of the required precision is available. Volume of a tree is generally estimated from three parameters: total tree height, diameter at 4 1/2 feet either inside or outside bark, and some measure of stem taper. Stem taper differences among trees are frequently ignored when volume equations are developed for young trees (Perry and Roberts, 1964, Schmitt and Bower 1970; Mohn and Krinard 1971). Stem taper differences among cottonwood (Populus deltoides Bartr.)clones conceivably could be large enough to result in volume estimation errors if such a general volume equation is used. In this paper, the stem attributes of nine clones and a nursery run lot were examined to determine (1) if there are differences in stem form between clones and (2) if general volume equations are of sufficient accuracy to rank clones in clonal test plantations and to accurately measure the response of a clone to experimental treatments such as fertilizer or irrigation.

MATERIALS AND METHODS

The data examined were obtained from measurements made on trees removed in thinning a test containing 9 clones and a nursery run lot. At the time of measurement, the sample trees were either 3 or 4 years old from cuttings and were growing in a replicated spacing-irrigation plot on the Texas A&M University farm in Burleson County, Texas. Approximately equal numbers of trees were sampled at years 3 and 4 from each of three spacings; 5' X 10', 6' X 12', and 7' X 14'. Sample trees were chosen on a mechanical basis to enlarge the 5' X 10' spacing to a 10' X 10' spacing, etc. The average number of trees sampled per

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[1/] Associate Geneticist, Texas Forest Service and Assistant Professor, TAES, College Station, Texas. The author expresses his appreciation to Mr. Chuck Carter, Champion International and Dr. J.P. van Buijtenen, Texas Forest Service for establishing the spacing-irrigation plot from which the sample trees used herein were removed.

clone was 33. The trees were felled at ground line and diameter measurements were made outside bark at 4.5 feet, 5 feet, and then every 5 feet until less than 5 feet remained in the tip of the tree. The length of the tip was recorded to the nearest tenth of a foot. The volume of each 5 foot section was calculated using Smalian's formula. The tip was treated as a paraboloid to determine its volume.

Form quotient values outside bark were calculated for each stem by dividing the stem diameter at a height midway between 4.5 feet and the top of the tree by the diameter at 4.5 feet. Bark thickness was not taken with the diameter measurements at the three and four year thinnings. In order to get an estimate of bark thickness, fifty standing trees of each of the nine clones and the nursery run lot were sampled at five years. Two bark thickness measurements were taken on opposite sides of the tree at 4 1/2 feet to the nearest twentieth of an inch and then averaged. The form quotient and bark thickness data were subjected to an analysis of variance.

A simple linear regression equation ($Y = a + b X$) was fitted to the data of the nursery run material and each of the nine clones by least squares regression. A simple linear regression through the origin ($Y = b X$) was also fitted to the ten sets of data. Actual total tree measured volume was the dependent variable and $(Dbh)^2$ times total height was the independent variable. All data were then combined to derive one single equation. In order to test for heterogeneity, the regression data were analyzed by a pooled regression procedure (iemmerle, 1967).

Two approaches were used to determine the relative accuracy of the combined equation and a volume equation previously published by Mohn and Krinard (1971). First, the pooled volume equation and the equation of Mohn and Krinard were used to estimate clonal cubic-foot stem volume outside bark for each sample tree. A mean predicted volume for each clone and each equation was then calculated. The clones were then ranked according to measured volume and predicted volume by the two equations. Secondly, the percent error was calculated for each clonal volume determination. Percent error was determined relative to the mean measured volume for the two equations as follows:

$$100 \times \{(\text{Predicted volume} - \text{measured volume})/(\text{measured volume})\}$$

RESULTS AND DISCUSSION

The mean heights and diameters, the range of heights and diameters within clones, and the mean volumes are given in Table 1. The average spread in heights within a clone was 17.3 feet, whereas the average diameter spread was 3.4 inches. Measured volume among clones ranged from .8 to 2.7 cubic feet.

Form quotient differences outside bark among the clones are evident (Table 2). The clone NE-316 has the largest form quotient (.70) while clone S13C3 has the smallest (.59). Bark thickness differences among the clones are also present (Table 2). The clone with the largest form quotient, NE-316, has the thinnest bark. The clone with the thickest bark, S4C2, has next to the smallest form quotient. The linear correlation between form quotient and bark thickness is quite high ($r = .88$) for this particular set of data and statistically significant at the .01 level. The r^2 value indicates that a large majority (77 percent) of the variability in the outside-bark form quotient differences is

Table 1.--Mean height, diameter and volume measurements for the nine clones and the nursery run lot

Clone	feet		inches		cubic feet
	mean height	height range	mean diameter	diameter range	mean measured volume
Alabama 11	32.0	20.0-40.5	3.1	1.7-5.2	.8
NE-316	33.4	25.0-40.0	3.0	1.8-4.1	.8
S4C2	34.0	29.5-41.0	4.0	3.0-6.4	1.3
S7C1	41.6	31.0-52.0	5.2	3.1-7.2	2.7
S7C3	40.6	28.0-48.5	4.9	2.6-6.5	2.3
S7C15	41.4	29.0-50.5	4.7	2.9-6.3	2.2
S7C16	40.3	30.0-48.0	4.3	2.1-5.5	1.8
S7C23	39.9	30.0-47.5	4.9	3.2-6.7	2.3
S13C3	37.2	32.5-42.5	4.5	3.6-6.1	1.6
Nursery run	35.6	27.5-44.0	4.2	2.7-6.4	1.6

Table 2.--Mean form quotient outside bark and bark thickness for the nine clones and the nursery run lot A/

Clone	Form Quotient	Clone	Bark Thickness
NE-316	.70 a	S4C2	.32 a
Alabama 11	.68 ab	S7C3	.27 b
Nursery run	.66 be	S7C16	.24 c
S7C16	.65 cd	S7C23	.24 c
S7C1	.64 d	S13C3	.24 c
S7C23	.64 d	S7C1	.24 c
S7C15	.63 de	Nursery run	.23 c
S7C3	.62 e	S7C15	.22 c
S4C2	.62 e	Alabama 11	.12 d
S13C3	.59 f	NE-316	.11 d
mean	.64	mean	.22

A/ Averages sharing a common letter within columns are not significantly different at the 5 percent probability level by the Duncan test.

associated with bark thickness differences among the clones. However, clones S7C15 and S4C2 have nearly identical form quotients but differ in bark thickness by .1 inches. Clones S7C1 and S13C3 have an identical bark thickness (.24") but differ by .05 in form quotient. Some differences among clones in stem form inside bark are suggested by these data.

The regression equation statistics for the 9 clones and the nursery run lot are given in Table 3. The variability among the regression statistics of the individual clones is sizeable, the Y intercept values ranged from .001 for clone S13C3 to .211 for clone S7C15. The regression coefficients ranged from .00191 for clone Alabama 11 to .00233 for clone NE-316. It is of interest to note that the tree size, the measured mean volume, the form quotient and bark thickness values of these two clones are very similar. However, the regression of volume on (Dbh) times height is very different for the two clones.

Table 3. --Regression equation statistics

Clone	# of sample trees	a	b	$y \cdot x$	r^2
Alabama 11	35	.143	.00191	.08	.96
NE-316	35	.039	.00233	.08	.95
S4C2	31	.103	.00201	.09	.98
S7C1	28	.048	.00220	.15	.99
S7C3	38	.025	.00222	.16	.97
S7C15	31	.211	.00201	.14	.98
S7C16	32	.192	.00207	.16	.94
S7C23	31	.126	.00214	.14	.98
S13C3	27	.001	.00212	.14	.94
Nursery run	41	.041	.00225	.09	.99
all combined	329	.075	.00216	.13	.98
Mohn & Krinard	650	.211	.00221	.28	.99

The variability among the regression statistics would indicate that the individual regressions should not be combined to arrive at a single equation. The pooled regression analysis confirms this (Hemmerle 1967). The slope of the regression lines and the intercepts of at least some of the clones were not equal. The coefficients of the two clones not native to Texas, Alabama 11 and NE-316, differed most noticeably from the other clones. The data for these clones were removed and the data reanalyzed for heterogeneity with seven clones and the nursery run lot. The statistical tests still indicated that all of the regression coefficients and the intercepts were not equal to each other. The analysis of the regressions through the origin indicated that the intercepts of five of the ten sets of data were equal to zero: these five sets of data all had intercepts beginning with zero (Table 3). Thus, pooling the data to get a combined equation is not strictly valid.

The variability among the clonal equations indicates that general equations derived from nursery run stock using only height and diameter would generally be unsuitable. However, deriving individual equations for each clone or calculating form factors for clones could be quite troublesome and expensive. General equations that were not too far in error would therefore be used. In this study, the pooled volume equation using all the data and the equation of Mohn and Krinard were used to predict clonal cubic-foot stem volume outside bark. The clones were then ranked (Table 4) according to actual measured volume and predicted volume. The clonal ranking remained essentially unchanged from the ranking obtained from measured volume. In some cases, accurate estimates of true volume production may be needed. Table 5 indicates the errors which resulted when the predicted clonal volumes were compared with the measured volumes.

Table 4.--Relative ranking of the nine cottonwood clones and the nursery run lot according to various methods of volume determination

Clone	Ranking		
	Actual measured volume	Predicted volume from combined equation	Predicted volume from equation of Mohn & Krinard
S7C1	1	1	1
S7C3	2	2	2
S7C23	2	2	2
S7C15	3	3	3
S7C16	4	4	4
S13C3	5	5	5
Nursery run	5	6	6
S4C2	6	7	7
NE-316	7	8	8
Alabama 11	7	8	8

Table 5.--Percent error [B/] in the volume determinations by the combined equation and the equation of Mahn & Krinard

Clone	Combined equation	Equation of Mohn & Krinard
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S7C1	- .7	+ 6.6
S7C3	- .4	+ 7.4
S7C23	-1.3	+ 7.0
S7C15	+ .5	+ 8.8
S7C16	-2.7	+ 7.1
S13C3	+6.8	+18.0
Nursery run	-1.9	+ 8.9
S4C2	+4.0	+17.6
NE-316	-2.6	+16.9
Alabama 11	+1.3	+20.8

[B/] Determined as $100 \times \frac{\text{(Predicted volume - measured volume)}}{\text{measured volume}}$

The percent error for the combined equation ranged from -2.7 for clone S7C16 to +6.8 for clone S13C3. The percent error for the equation of Mohn and Krinard ranged from +6.6 for clone S7C1 to +20.8 for clone Alabama 11. The clones with the largest percent error for the Mohn and Krinard equation are those clones having low and high form quotient values.

SUMMARY AND CONCLUSIONS

The outside-bark form quotient varied from .59 to .70 in these young cottonwood clones. A close linear correlation (r = .88) was found between clonal form quotient and bark thickness. The data obtained here suggest that cottonwood clonal differences in form quotient inside bark in young trees are probably small. These results parallel those found by Pederick (1970) for families of loblolly pine (Pinus taeda L.).

When individual regressions were run on the nine clones and the nursery run lot, there was sizeable variability among the regression coefficients and the Y intercepts. Statistical tests indicated that the slopes of the regression lines of the ten individual equations were not equal. The Y intercept value for five of the ten sets of data was equal to zero. Thus, a combined equation pooling all the data was not statistically valid. However, in this study with these particular clones, cubic foot volumes estimated from the combined equation and an equation published by Mohn and Krinard ranked the clonal lines for stem volume relative to measured volume accurately enough for the purpose of the study. The equal utility of these two equations suggests that in general among clone form differences outside bark may not be sufficiently large to seriously affect ranking clones for total stem volume. Conversely, accurate estimates of clonal volume production were not obtained with the combined equation and the equation of Mohn and Krinard. If an accurate estimate of actual wood volume production of an individual clone in response to some experimental treatment is wanted, then individual clonal equations or equations involving form based on inside bark measurements will be required.

LITERATURE CITED

Hemmerle, W.J. 1967. Statistical computations on a digital computer. Blaisdell Publishing Company, Waltham, Mass. 230 pp.

Mohn, C.A. and Krinard, R.M. 1971. Volume tables for small cottonwoods in plantations. U.S. Forest Ser. Res. Note SO-113, 4 p. South. Forest Exp. Sta., New Orleans, Louisiana.

Pederick, L.A. 1970. Variation and inheritance of stem form and bark thickness in young loblolly pine. Tech. Rept. 41, School of Forest Resources, N.C. State Univ., Raleigh. 49 pp.

Perry, T.P. and Roberts, A.Y. 1964. Volume formulas for loblolly pine seedlings in the vicinity of Raleigh, North Carolina. J. Forest. 62:186-187.

Schmitt, D. and Bower, D. 1970. Volume tables for young loblolly, slash, and longleaf pines in plantations in south Mississippi. U.S. Forest Ser. Res. Note SO-102, 3 p. South. Forest Exp. Sta. New Orleans, Louisiana.