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PREDICTING BOARD-FOOT TREE VOLUME FROM STUMP DIAMETER FOR EIGHT HARDWOOD SPECIES IN OHIO[1]

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ABSTRACT. Regression equations were developed to predict volume table values for merchantable gross volume from stump diameter for eight species of hardwood trees in south-central Ohio. Mesavage and Girard's volume tables were used to develop equations for both the Doyle and International ¼" log rules. Data for the study were collected in Scioto Co., Ohio. Regression equations were weighted by the inverse of estimated variances. The range in R^2 was from 0.82 to 0.96. Both equations and tables are presented for each species and for combined equations.

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INTRODUCTION

The board-foot volume content of a tree is normally estimated using traditional volume tables or equations which require the measurement of both tree diameter breast height (DBH) and merchantable height. However, in certain situations, such as timber theft or lost or unrecorded data from harvested stands, trees have been removed and cannot be measured. In such situations volume must be estimated from stump measurements.

Previous studies have been conducted to determine relationships between DBH and stump diameter (Bylin 1982a, Curtis and Arney 1977, Raile 1978). Results of these studies are used to estimate tree volume indirectly by using local volume tables or equations. Such a procedure assumes the existence of local volume tables which often is not the case. This procedure also requires two estimations, DBH and volume, each a source of variation.

Literature on predicting volume directly from stump diameter is quite sparse (Bylin 1982b, Quigley 1954, Nyland 1975). In this report we develop equations to predict volume in board feet for both the Doyle and International ¼" log rules.

METHODS AND MATERIALS

Data were collected on the Mead Experimental Forest located in northern Scioto Co. in south-central Ohio. Tree diameter breast height, stump diameter, and merchantable height were measured on all trees (n = 573) 29.5 cm DBH and larger growing on 22 0.2-ha plots. Plots had not been cut for at least 20 yr. Black oak site index (base age 50 yr) on plots ranged from 63 to 80 (Carmean 1964) and basal area ranged from 16 to 30 m^2 per ha for trees 9.1 cm DBH and larger.

Tree diameter to the nearest 0.254 cm was measured with a steel diameter tape at 0.3 m (stump height) and 1.07 m (breast height) above ground on the uphill side. Merchantable height to a 25.4-cm outside bark top diameter was measured to the nearest 0.3 m (excluding a 0.3 m stump) with a Spiegel-Relaskop. Individual tree gross volume was determined for both the Doyle and International ¼" log rules using volume tables by Mesavage and Girard (1946). Form class 78 volume tables were used for all species except ash, for which form class 82 was used.

Species measured included white oak (*Quercus alba*), chestnut oak (*Q. prinus*), scarlet oak (*Q. coccinea*), black oak (*Q. velutina*), northern red oak (*Q. rubrum*), yellow poplar (*Liriodendron tulipifera*), hickory (*Carya* spp.), and ash (*Fraxinus* spp.). The total numbers of trees of each species measured are given in tables 1 and 2.

The form of the equation which best fit the data for each log rule was determined by linear regression using the data for each species. RSQUARE procedure (SAS 1979) was used to calculate the R^2 for one-to-four variable linear models which included

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TABLE 1

*Doyle log rule volume equations**.

Species	Coefficients** *a*	*b*	*c*	R^2	n	Stump Diameter*** Range (cm)
White oak	535.3	70.91	19.46	.84	184	33-85
Scarlet oak	355.0	53.62	15.30	.88	106	34-72
Chestnut oak	538.4	76.26	21.28	.88	104	33-71
Yellow poplar	253.0	52.48	16.16	.95	60	31-73
Black oak	572.1	74.76	20.48	.84	59	33-68
Hickory	36.2	22.72	7.74	.84	24	35-70
Ash	149.1	38.43	12.26	.90	19	33-60
Northern red oak	770.6	100.63	27.35	.96	17	35-62
Black oak, white oak, scarlet oak, & hickory	463.1	63.78	17.74	.84	373	33-85

*$Volume = a - b(SD) + c(SD)^{1.3}$, where volume is in board feet to a 25.4-cm top outside bark and stump diameter is in centimeters.

**To obtain equations to predict volume Doyle from stump diameter measured in inches, multiply coefficients *b* and *c* by 2.54 and 3.36, respectively.

***Stump height of 30.5 cm above ground.

TABLE 2

*International ¼" log rule volume equations**.

Species	Coefficients** *a*	*b*	*c*	R^2	n	Stump Diameter*** Range (cm)
White oak	631.2	232.72	151.71	.82	184	33-85
Scarlet oak	232.2	134.29	90.85	.88	106	34-72
Chestnut oak	497.5	230.00	142.64	.86	104	33-71
Yellow poplar	43.8	116.22	82.89	.95	60	31-73
Black oak	834.1	282.80	182.99	.84	59	33-68
Hickory	−114.0	48.70	37.62	.80	24	35-70
Ash	− 40.0	79.49	58.35	.87	19	33-60
Northern red oak	816.1	306.26	199.41	.96	17	35-62
Black oak, white oak, scarlet oak, & hickory	528.9	206.30	135.36	.83	373	33-85

*$Volume = a - b(SD) + c(SD)^{1.1}$, where volume is in board feet to a 25.4-cm top outside diameter and stump diameter is in centimeters.

**To obtain equations to predict volume Doyle from stump diameter measured in inches, multiply coefficients *b* and *c* by 2.54 and 2.7882, respectively.

***Stump height of 30.5 cm above ground.

stump diameter raised to powers ranging from one to 10 in one-tenth increments. Because of the excellent fit of the linear models, other equation forms were not examined.

Tree volume variance was not homogeneous over the diameter ranges. To correct for this, regression equations for predicting volume of each species from stump diameter were weighted by the inverse of estimated volume variances (Freese 1964). Volume variances for each log rule were estimated with equations developed by grouping data for each species into 2.54-cm stump diameter classes. Equations to estimate volume variance by diameter class were then derived using the procedure described above for deriving the volume prediction equations but including models with the intercept equal to zero. The inverse of the appropriate volume variance was then used to weight each observation in developing the equations to predict volume from stump diameter. Doyle volume variance was estimated by the equation

$$s^2 = .00000039(SD)^{5.6}$$

where s^2 was volume variance and SD stump diameter. International 1/4" volume variance was estimated by the equation

$$s^2 = .00008989(SD)^{4.4}$$

Covariance analysis (P = .05) was used to test for significant differences between species volume equations (Freese 1964). Data for species equations that were not significantly different were combined into one equation for each log rule.

RESULTS AND DISCUSSION

The model producing the highest r^2 for the weighted regression for the Doyle log rule was

$$Volume = a - b(SD) + c(SD)^{1.3}$$

where a, b, and c are constants that vary with species, SD is stump diameter in centimeters 0.3 m above ground, and *volume* is in board feet to a 25.4-cm top diameter outside bark. The model producing the highest R^2 for the weighted regression for the International ¼" log rule was

$$Volume = a - b(SD) + c(SD)^{1.1}$$

There was no significant gain in R^2 with higher order equations. Equation coefficients for each species to predict volume Doyle and International ¼" from stump diameter are shown in tables 1 and 2, respectively. Doyle and International ¼" volume by species by stump diameter based on these equations are presented in tables 3 and 4, respectively.

Covariance analysis revealed that equations for black oak, scarlet oak, white oak,

TABLE 3

Local volume table by stump diameter for south-central Ohio based on the Doyle log rule**.*

Stump diameter***	White oak	Scarlet oak	Chestnut oak	Yellow poplar	Black oak	Hickory	Ash	Northern red oak	White oak, scarlet oak, black oak, & hickory
cm	board feet volume to 25.4 cm top diameter outside bark								
33.02	29	27	27	44	34	16	36	27	30
35.56	35	36	36	65	39	32	56	32	37
38.10	44	49	50	89	49	50	78	43	48
40.64	58	65	67	116	63	69	102	59	62
43.18	75	84	89	147	80	89	129	80	80
45.72	95	105	115	180	101	111	157	107	100
48.26	119	130	144	216	126	135	188	138	124
50.80	146	156	177	255	154	160	221	174	151
53.34	177	185	213	296	186	186	256	214	181
55.88	210	217	253	340	220	213	293	258	213
58.42	246	251	296	386	258	241	332	306	249
60.96	285	287	342	435	299	270	372	359	286
63.50	327	325	391	486	342	301	414	415	327
66.04	372	365	443	539	389	333	458	475	369
68.58	419	408	497	595	438	365	504	539	414
71.12	469	452	555	652	490	399	551	606	462
73.66	521	499	615	712	544	433	600	677	511
76.20	575	547	678	773	601	469	650	751	563
78.74	632	597	743	837	660	506	702	829	617
81.28	691	649	811	902	722	543	755	909	673
83.82	753	702	882	969	787	581	809	993	737

*Stump height 30.5 cm above ground.
**Bold lines indicate extent of observed data.
***Stump diameter measurements in even inches, unit most commonly used by forestry practitioners and researchers (i.e. 33.02 cm = 13 in, 35.56 cm = 14 in, etc.).

TABLE 4

Local volume table by stump diameter for south-central Ohio based on the International 1/4 inch log rule**.*

Stump diameter***	White oak	Scarlet oak	Chestnut oak	Yellow poplar	Black oak	Hickory	Ash	Northern red oak	White oak, scarlet oak, black oak, & hickory
cm	board feet volume to 25.4 cm top diameter outside bark								
33.02	54	54	53	89	68	40	69	45	58
35.56	66	74	72	124	78	66	99	60	72
38.10	83	97	95	160	93	93	131	82	91
40.64	104	122	123	200	113	121	165	108	113
43.18	129	150	153	241	137	150	200	140	138
45.72	157	180	188	284	166	180	236	176	167
48.26	189	212	225	329	199	211	274	217	199
50.80	224	246	266	376	236	243	313	262	233
53.34	262	281	309	425	277	275	353	311	271
55.88	304	319	356	475	321	308	394	365	311
58.42	348	358	405	527	369	342	437	422	354
60.96	395	399	456	580	421	377	480	483	399
63.60	444	442	510	635	475	412	525	565	447
66.04	496	486	567	691	533	448	570	614	497
68.58	551	532	626	749	593	484	617	685	549
71.12	608	579	687	808	657	521	664	759	603
73.66	668	627	750	868	723	559	712	836	659
76.20	729	667	816	929	792	597	761	916	718
78.74	793	728	883	992	863	636	811	999	778
81.28	859	780	953	1056	938	675	862	1085	840
83.82	927	834	1024	1121	1014	715	914	1173	904

*Stump height 30.5 cm above ground.
**Bold lines indicate extent of observed data.
***Stump diameter measurements in even inches, unit most commonly used by forestry practitioners and researchers (i.e. 33.02 cm = 13 in, 35.56 cm = 14 in, etc.).

and hickory were not significantly different, and they were combined into a single equation. The equation for chestnut oak was significantly different from the other upland oaks and was not included in the composite equation. This species grouping appeared to have resulted, at least in part, from differences among species in lower trunk taper. White oak, scarlet oak, black oak, and hickory had similar lower trunk tapers, with differences between stump diameter and DBH averaging 8.4, 7.9, 7.4, and 7.1 cm, respectively. Chestnut oak had significantly less lower trunk taper ($P = .05$) than white, scarlet or black oak, with a 6.4-cm average difference between stump diameter and DBH. It should be noted that with greater numbers of observation the hickory curve might prove significantly different from the oaks. The hickory curve begins to fall below the oak curve at about 58 cm stump diameter.

Quigley's (1954) study estimating tree volume from stump diameter for trees in Ohio and Indiana provides the only published study suitable for comparison. Volumes predicted by equations developed in this study are higher than those predicted by Quigley for "average" trees in Ohio and Indiana. Data used in Quigley's analysis were collected from trees located on a wide range of sites throughout Ohio and Indiana. Apparently trees in this study have lower stump to DBH ratios and/or greater merchantable height than the average tree over Ohio and Indiana. Such geographic variation emphasizes the importance of having equations or tables developed in the region of use.

Equations developed in this study may

be used directly to estimate tree volume, as when a computer or programmable calculator are being used to summarize or analyze data. In other situations, tree volume can be estimated directly from tables 3 and 4. Where tree species can be determined, individual species equations or tabled values should be used rather than the composite.

Several cautions should be observed in applying the equations or tables. First, the equations are predicting the volume of the "average" tree of a particular species and stump diameter. Application of an equation to an individual tree may result in a volume estimate very different from that tree's actual volume. Application of the equations to a group of trees, however, should provide reliable estimates of their volume. Second, care should be taken in applying the equations and tables beyond the range of stump diameters over which they were developed (tables 1 and 2). Equations were selected to predict volume from stump diameter within a specific range of stump diameters and may not accurately estimate volume beyond that range. Finally, it should also be noted that volume variability is greater for larger diameter trees.

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