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TOTAL CUBIC VOLUME TABLE FOR WHITE SPRUCE PLANTATIONS DRUMMONDVILLE, QUEBEC

by S. Popovich

LAURENTIAN FOREST RESEARCH CENTRE
QUEBEC REGION, QUEBEC
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ABSTRACT

Data for estimating total volume in cubic feet for white spruce, *Picea glauca* (Moench) Voss plantations, established between 1940 and 1945 on abandoned farmland near Drummondville, Quebec (Forest Section L3), is determined, with a method for preparing volume tables for plantations or natural stands using normal form factors.

RESUME

Ce rapport fournit les données pour évaluer le volume de bois total dans les plantations d'épinette blanche, *Picea glauca* (Moench) Voss établies de 1940 à 1945 sur des terres abandonnées de la région de Drummondville (Section forestière). Une méthode pour la construction des tarifs de cubage des plantations et des peuplements naturels, en employant le coefficient de forme normale, est aussi présentée.

INTRODUCTION

White spruce, *Picea glauca* (Moench) Voss and red pine, *Pinus resinosa* (Ait.), are two forestry species most commonly planted in Quebec province. The two largest plantations of white spruce are in Forest Section L3 (Rowe, 1959), in the northern part near Grand'Mère, and in the south near Drummondville.

It is known the growth of trees in plantation generally differs from natural stands; because of variations in tree form the volume of wood differs. Existing volume tables, therefore, cannot be applied for white spruce in plantation, and, because of productivity difference in Quebec, volume tables for white spruce in other provinces cannot be used.

Productivity evaluation of plantations younger than 50 years requires accurate volume tables (Popovich and Houle, 1970); this report is an attempt to construct tables that are as accurate as those constructed by conventional methods, but require fewer sample trees and less analysis. Construction of the tables was built on the normal form factor (Zaharov, 1964 and Golovatchev, 1967), and was the most satisfactory for productivity evaluation.

The work was undertaken to provide better standards for evaluating the total cubic volume for white spruce plantations in the southern part of Forest Section L3, and a rapid, accurate method for constructing the tables.

MATERIAL AND METHODS

All stands sampled were on a plantation belonging to the Southern Canada Power Company (now Hydro-Quebec) at Drummondville, Quebec. Study trees were selected from four pure white spruce plantations, established between 1940 and 1945 on abandoned farmland. According to the productivity classification established by Popovich and Houle (1970), based on the volume per square foot of basal area, the plantations belong to productivity classes II and III, or as Stiell and Berry (1967) determined, they correspond to site index classes 60 and 50, based on dominant height. Initial spacing for the four plantations was 4 x 6, 5 x 5, 6 x 6, and 7 x 7 ft.

Field work

Sixty-five per cent of the 121 trees felled and measured were removed during thinning operations, and 35% felled for use in this study. Size varied from 2 to 10 inches d.b.h. For each d.b.h. class an average of 13 trees were felled.

Measurements on each felled tree were:
d.b.h. to nearest 1/10 inch; total height to nearest 1/10 ft; diameter at stump (d_0), 5 ($d_{0,05}$), 10 ($d_{0,1}$), 20 ($d_{0,2}$)... and 90 ($d_{0,9}$) % of total height.

Bark thickness of all sampled trees was calculated according to Form Class Volume Tables (Anonymous, 1948; Berry (1969) confirmed the accuracy of these tables.

Volume table method of construction

To determine tree volume, a breast high form factor is normally used, that is, the ratio between the volume of a tree and the volume of a cylinder having a diameter equal to the d.b.h.

and the same height

$$V = \frac{\pi d^2 \ \ hf}{4} = g_{4,5}\ hf \tag{1}$$

where

V = volume of the central stem

$g_{4,5}$ = basal area at breast height

h = total height of tree

f = breast high form factor.

The form factor value for a tree is obtained by dividing the actual volume of a tree by the volume of a cylinder having a diameter equal to the d.b.h. of the tree and the same height

$$f = \frac{V\ tree}{g_{4,5}\ h} \tag{2}$$

Although this form factor gives consideration to tree height, form, and age, Zaharov (1964) points out it does not describe the true form of stems when applied to trees of superior height. He states this disadvantage can be avoided by using a normal form factor in calculating the volume of trees, rather than the breast high form factor. The same author defines the normal form factor as the ratio between the volume of a tree and the volume of a cylinder of equal height, but with different diameters. The cylinder diameter is taken at 10% of the tree height, and the tree diameter at 50% of its height.

Thus, the volume of the cylinder is expressed by $Vc = \frac{\pi d^2_{0,1}\ h}{4}$ and that of the tree by $Vt = \frac{\pi d^2_{0,5}\ h}{4}$. Therefore the normal factor is:

$$fn = \frac{V\ tree}{V\ cylinder} = \frac{\frac{\pi d^2_{0,5}}{4} h}{\frac{\pi d^2_{0,1}}{4} h} = \frac{d^2_{0,5}}{d^2_{0,1}} = q^2_{0,5/0,1} \qquad (3)$$

Zaharov (1964) maintains the normal form factor is more desirable than the breast form factor, because it takes into consideration form differences of different species, and not only height, diameter, and age.

In this study, the cubic volume of each felled tree was calculated by the Golovatchev (1966) formula

$$V = \frac{\pi d^2_{0,1}}{4} \frac{(h)}{10} \left(q^2_{0,05} + \frac{q^2_{0,1}}{2} + q^2_{0,2} + \ldots + q^2_{0,9}\right) \qquad (4)$$

where $d_{0,1}$ is the diameter measured at 10% of the total height (h) of the tree, and where $q_{0,5}$, $q_{0,1}$, $q_{0,2}$, ...$q_{0,9}$ refers to form indexes of the stem based on diameters taken at 5, 10, 20... 90% of the total tree height.

Golovatchev's formula can be demonstrated as: the tree, divided into 10 equal sections $\frac{(h)}{10}$, its volume (V),is estimated by the equation

$$V = \left(\frac{\pi d^2_{0,05}}{4} + \frac{\pi d^2_{0,1}}{8} + \frac{\pi d^2_{0,2}}{4} + \ldots \frac{\pi d^2_{0,9}}{4}\right) \frac{h}{10} \qquad (5)$$

Equation (5) needs explaining. It is evident the volume (V) is based on the sum of discrete volumes. These are considered as cylinders of corresponding sections, having a base $\frac{\pi d^2_1}{4}$. These tree sections represent the base section of a cone, hence equation (5) could have produced an 'overcubage' if it had not been modified by its two first terms,

$$\frac{\pi d^2_{0,05}}{4} \quad \text{and} \quad \frac{\pi d^2_{0,1}}{8}$$

The first term $(\frac{\pi d^2_{0,05}}{4})\frac{h}{10}$ is a cylinder, the base of which is equal to the median section of the basal section of a stem: $d_{0,05}$ in fact is equidistant from the stump and $d_{0,1}$. Consequently, a valid, unbiased estimation of real volume of this section is provided, analogous to the estimation made by Newton's classic formula.

The second term of equation (5) $(\frac{\pi d^2_{0,1}}{8})\frac{h}{10}$ represents only half the volume of the second section. This reduction compensates for overcubage in the upper sections $(\frac{\pi d^2_{0,3}}{4})\frac{h}{10}$;

$\frac{\pi d^2_{0,2}}{4}\ \frac{h}{10}$, etc. Results obtained by formula (5) compare favorably with those of Newton (8).

Continuing to demonstrate the method for construction, the normal form factor volume tables of Golovatchev (1967), equation (3), $\frac{d^2_{0,5}}{d^2_{0,1}} = q^2_{0,5}/_{0,1}$ can be generalized as

$$\frac{d^2n}{d^2_{0,1}} = q^2n/_{0,1} \tag{6}$$

where d^2n is the diameter of n-tieth section and where $q^2n/_{0,1}$ is the form index of the stem considered for different heights (n).

From (6) comes equation (7)

$$d^2n = d^2_{0,1} \cdot q^2n/_{0,1} \tag{7}$$

So, for example, $d^2_{0,05} = d^2_{0,1} \cdot q^2n/_{0,1}$.

Replacing in formula (5) the values of square diameters by values expressed in formula (7) equation (4) is found again.

The cubic volume of each 121 felled trees was also calculated by Newton's formula (Husch, 1963):

$$V = 0.003636\ h\ [(\frac{d^2{}_0}{2}) + 2d^2{}_1 + d^2{}_2 + \ldots\ 2d^2{}_7 + (\frac{5d^2{}_8}{4}) + (\frac{3d^2{}_9}{4})] \quad (8)$$

This formula was used to check the accuracy of formula (4).

The normal form factor of each felled tree was calculated by the formula:

$$fn = \frac{q^2{}_{0,05} + \frac{q^2{}_{0,1}}{2} + q^2{}_{0,2} + \ldots + q^2{}_{0,9}}{10} \quad (9)$$

Formula (9) is derived from formula (4). As the cubic volume of a tree is composed of three magnitudes:

$$V = g_{0,1} \cdot hf_{0,1} \quad (10)$$

(V = cubic volume; $g_{0,1}$ = basal area of diameter taken at 10% of the height, and h = total height) the normal form factor will be:

$$fn = \frac{V}{g_{0,1}h} = \frac{V}{\frac{\pi d^2{}_{0,1}h}{4}} \quad (11)$$

If the numerator in formula (11) is replaced by the right side of equation (4), after some reductions formula (9) is obtained, *i.e.*, the formula of normal form factor of each felled tree.

Three linear regression curves were made for the 121 felled trees to quantify the relationships and estimate the degree of association between d.b.h. and $d_{0,1}$; d.b.h. and $d_{0,5}$; $q_{0,5}$ and $f_{0,1}$(normal form factor) calculated by formula (9).

The three equations are (Figs. 1, 2, and 3):

$$d_{0,5} = 0.2254 + 0.6502\ \text{d.b.h.} \quad [r = 0.94] \tag{12}$$

$$d_{0,1} = 0.3623 + 0.9979\ \text{d.b.h.} \quad [r = 0.96] \tag{13}$$

$$f_{0,1} = 0.09526 + 0.58131\ q_{0,5} \quad [r = 0.88] \tag{14}$$

As a result of the close relationship between $f_{0,1}$ and $q_{0,5}$ (14), their ratio is defined as parameter F

$$F = \frac{q_{0,5}}{f_{0,1}} \tag{15}$$

or

$$f_{0,1} = \frac{q_{0,5}}{F} \tag{16}$$

If, instead of $f_{0,1}$ in the formula of cubic volume of each tree ($V = \frac{\pi d^2_{0,1}}{4} \cdot h \cdot f_{0,1}$) the right side of formula (16) is used, and $q_{0,5}$ is replaced by its substituting ratio ($d_{0,5}/d_{0,1}$), then after some reductions the mathematical expression

$$V = \frac{\pi}{4F} \cdot d_{0,1} \cdot d_{0,5} \cdot h \tag{17}$$

is obtained.

Replacing π: $4F = 0.785\ F^*$ (18)

by parameter A, the general formula for calculating the cubic volume of felled trees is obtained,

$$V = A \cdot d_{0,1} \cdot d_{0,5} \cdot h \tag{19}$$

Real magnitude of the average normal form quotient ($q_{0,5}$), which represents the four plantations studied, and calculated for 121 trees, is 0.6496 or 0.65. (Confidence interval ranges from 0.6403 to 0.6589 at the probability level of 0.05.)

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* 3.1416: 4 = 0.785

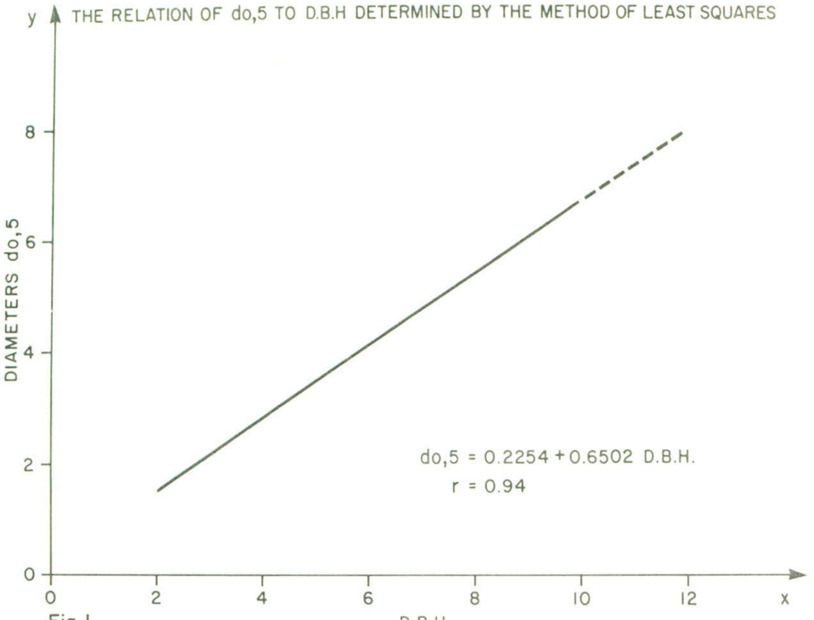


Fig. I

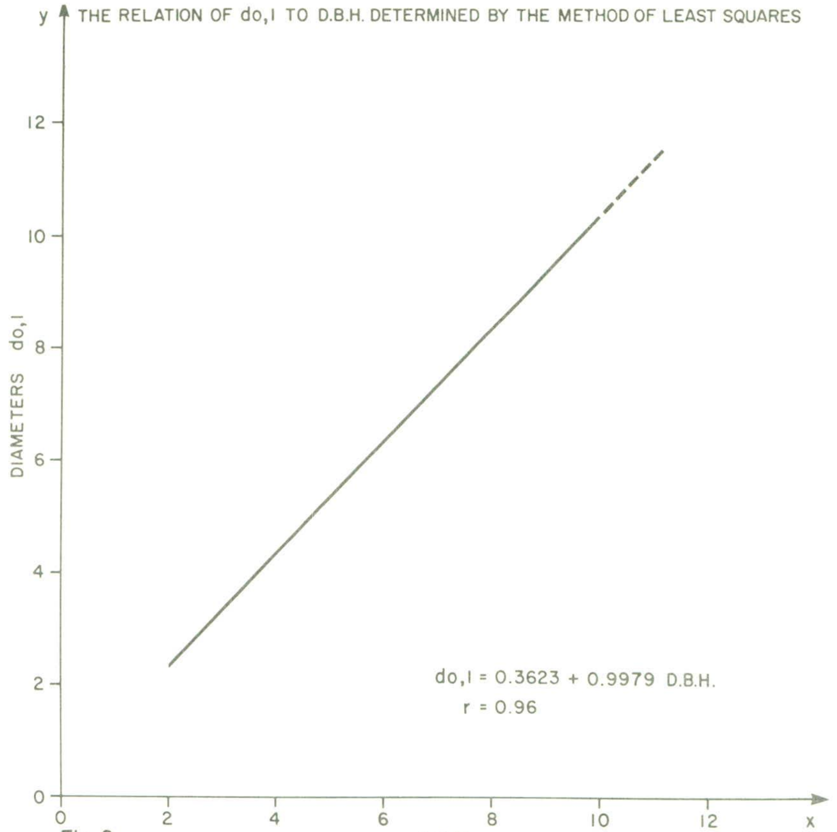


Fig. 2

Fig. 1 - The relation of $d_{0,5}$ to d.b.h., and *Fig. 2* the relation of $d_{0,1}$ to d.b.h., and *Fig. 3* the relation of $f_{0,1}$ to $q_{0,5}$ are all determined by the method of least squares.

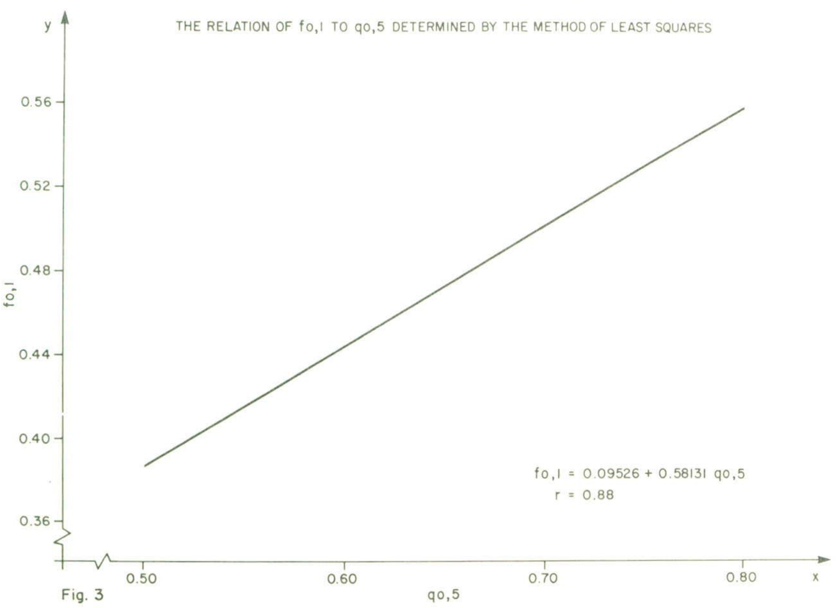


Fig. 3

Having introduced it in formula (14) and resolved the equation, the average normal form factor for four plantations was 0.473. By means of this factor, formulas (15) and (18) were resolved, and as final result the average parameter A = 0.571 was obtained. Introducing the numerical value of this parameter into formula (19), it changes and becomes

$$V = 0.571.\ d_{0,1}.\ d_{0,5}\ .h \qquad (20)$$

The value of V must be divided by 144 to obtain volume in cubic feet where h is expressed in feet and d in inches.

With formula (20) the cubic volume of all felled white spruce trees (bark included) originating from plantations at Drummondville can be calculated.

The practical value of formula (20) is limited to calculations on felled trees. To use it for determining the cubic volume of standing trees, some mathematical transformations are necessary.

Having multiplied the right side of equation (20) with mathematical expression $\left(\frac{d_{0,1}}{d_{0,1}}\right)$ the volume becomes

$$V = 0.571\ d^2_{0,1}\ \frac{d^2_{0,5}}{d_{0,1}}\ .h \qquad (21)$$

Since $\left(\frac{d_{0,5}}{d_{0,1}}\right) = q_{0,5}$, formula (21) is further modified into

$$V = 0.571.d^2_{0,1}\ .q_{0,5}\ .h \qquad (22)$$

Multiplying ($q_{0,5}$), already determined as 0.65, with the value of parameter A (0.571), the equation (22) evolves into

$$V = 0.371\ d^2_{0,1}\ .h$$

The last step of this transformation is to include the linear regression (13) into equation (23) to achieve

$$V = 0.371\ (0.3623 + 0.9979\ d.b.h.)^2\ .h \qquad (24)$$

Resolving this binominal expression and multiplying it by the factor 0.371, formula (24) becomes

$$V = \frac{(0.049 + 0.268\ d.b.h. + 0.369\ d.b.h.^2)\ h}{144} \qquad (25)$$

Where

V = volume in cubic feet

d.b.h. = diameter at the breast height

H = total height of a tree.

With formula (25) the total volume table (bark included) was constructed (Table 1). Based on Table 1 facts, Table 2 was constructed; its practical value is in estimating the total volume in cubic feet (inside bark) for all white spruce plantations at Drummondville.

For calculating the average taper rate of all felled trees, equation (6) was applied. Each diameter of a felled tree from $d_{0,05}$ to $d_{0,9}$ was divided by the diameter at 10% of the tree height $(d_{0,1})$ was divided by the diameter at 10% of the tree height $(d_{0,1})$. All data from this calculation was tabulated by sections of trees, and all statistical data concerning variability in each section from the average taper rate, were calculated according to Hellrigl (1970).

By means of the average taper rate, average diameter, and the average height (taken from the 121 felled trees), the average tree was determined (Fig. 4). The corresponding average height was taken from the height-diameter curve representing 771 trees (Fig. 5).

Linear relationships between the volume of each of the 121 trees calculated by formula (25) and by Newton's formula (8) were discovered. To verify this relationship, the correlation coefficient, and the standard error of estimate were calculated.

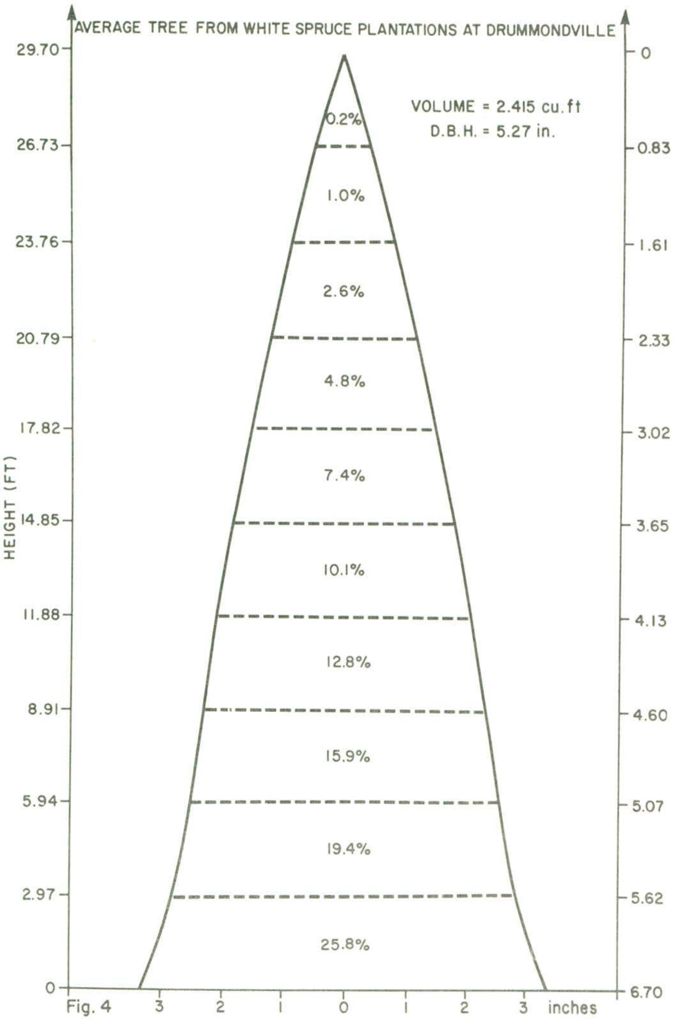
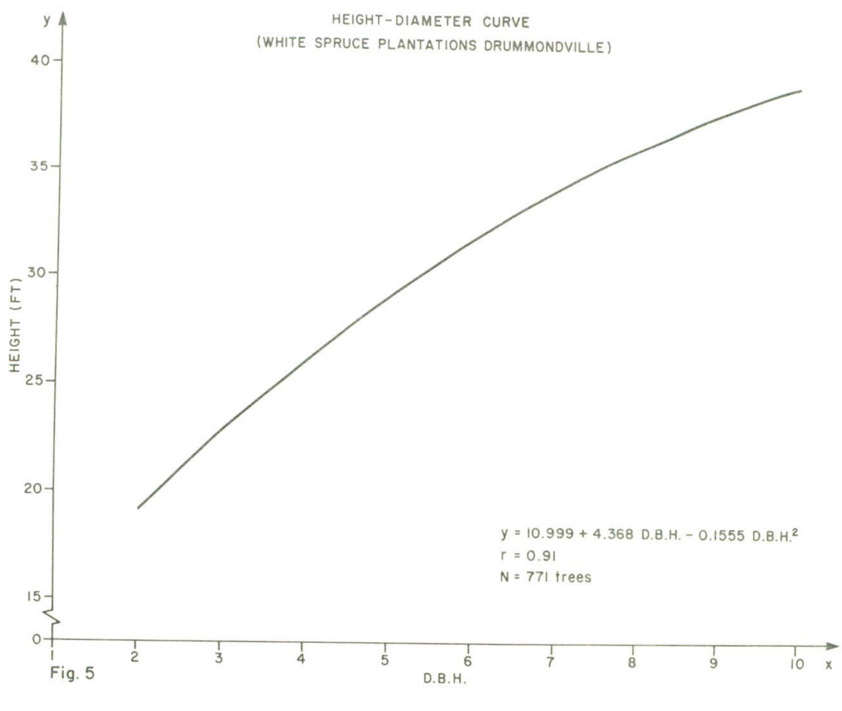


Fig. 4 - Average tree from white spruce plantations at Drummondville, divided into 10 equal parts; percentage participation of each part is shown in the total volume.

Fig. 5 - Height-diameter curve for white spruce plantations at Drummondville, Quebec.



For the data used in constructing the table, the tabular volume estimate is within plus or minus n units of the volume. For example, the tabular estimates of total cubic feet volume for individual white spruce was within plus or minus 8% of the true volume 95% of the time.

RESULTS AND DISCUSSION

Average tree form

The average taper rate calculated for all felled trees is given in Table 3. Data concerning the taper rate of all felled trees are grouped and tabulated together, because the average values of taper rates of all sample plots did not show any significant difference when reciprocably tested. (In all cases, the t' value was below 1.4 at probability level 0.05, and with 30 and 39 degrees of freedom.)

Although Table 3 was calculated from samples ranging from 2 to 10 inches d.b.h., from 15 to 45 ft in height, and from 23 to 30 years, it shows the taper rates of the 121 trees are well grouped around their average expression. If a 10% coefficient of variation is established as a limit, then the largest disparity from the average expression occurs in the last three deciles of the total height of the tree, *i.e.*, in the two upper logs and tip. These three sections contribute about 3.8% of the total tree volume (Fig. 1). The average tree examined in this study had a volume of 2.410 ft^3, with only 0.092 ft^3 in the upper two logs and tip. In Table 3, it is also shown that the paraboloid is less tapering, or more full-bodied, than the average white spruce tree, resulting in a 17% greater volume for paraboloid.

Discussion of equation

Table 4 shows the real average volumes with confidence intervals presented with estimated volumes and deviation percentages for white spruce plantations at Drummondville.

It has been stated that construction of a total volume table was made by equation (25). With this equation the following equalized effects are obtained:

(1) Sum of estimated volumes equals that of real volumes;

(2) Estimated volumes are always contained within the limits of the average real volume;

(3) Standard error of estimate is 0.277 ft^3 and correlation coefficient r = C.99.

Volume tables

Table 1 presents the total volume in cubic feet (bark included) and Table 2 presents the total volume in cubic feet (inside bark) for white spruce plantations at Drummondville.

Comparing Table 2 with the tables of Honer (1967) (natural white spruce stands) and Berry (1969) (white spruce plantations), it can be seen there is no difference between Honer's table and Table 2 in this study, and that they show 6% greater volume than Berry's.

Table 5 shows the volumes obtained from six sample plots in the Drummondville white spruce plantations (Popovich and Houle, 1970), using the volume tables of Berry, Honer, and Popovich. From this table, it can also be seen that natural white spruce stands, with equal height and basal areas, produce as much wood as white spruce plantations in early age at Drummondville. Without making a conjecture, it seems that the form quotient of Drummondville plantations do not differ from the form quotient of corresponding natural stands.

CONCLUSIONS

1. Table 2 can be used for calculating the total cubic foot volume of almost all white spruce plantations situated within the southern part of Forest Section L3 (Rowe, 1959). Its use can also be extended to calculate the current total volume increment in these plantations.

2. Construction of the volume tables in relation to other methods is very simple, they require half as many sample trees for stem analysis. The economic advantage of using the normal form factor for the construction of volume tables instead of breast high form factor is obvious.

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TABLE 1

Total volume table (bark included) for white spruce

(*Picea glauca* (Moench) Voss)

d.b.h. (over bark)	Total tree height (ft)							
	15	20	25	30	35	40	45	50
	Total volume ft^3 (stump, top,and bark included)							
inch								
2	.215	.286	.358					
3	.435	.580	.724	.869				
4		.976	1.22	1.46	1.71			
5		1.47	1.84	2.21	2.58	2.95		
6		2.07	2.59	3.11	3.63	4.15	4.67	
7			3.47	4.17	4.86	5.56	6.25	6.95
8				5.38	6.27	7.17	8.06	8.96
9					7.86	8.99	10.11	11.23
10					9.63	11.01	12.38	13.76
11						13.23	14.89	16.54

$$\text{VTCF} = \frac{(0.049 + 0.268 \text{ d.b.h.} + 0.369 \text{ d.b.h.}^2)\ H}{144}$$

Basis 121 trees (Drummondville plantations)

Accuracy 5% level (% + or - 8.0)

TABLE 2

Table volume table (bark not included) for white spruce

(*Picea glauca* (Moench) Voss)

d.b.h. (over bark)	Total tree height (ft)						
	15	20	25	30	35	40	45
	Total volume ft^3 (stump, top included, inside bark)						
inch							
2	.191	.255	.319				
3	.387	.516	.644	.773			
4		.869	1.09	1.30	1.52		
5		1.31	1.64	1.97	2.30	2.63	
6		1.84	2.30	2.77	3.23	3.69	4.16
7			3.09	3.71	4.32	4.95	5.56	6.19
8				4.79	5.58	6.38	7.17	7.97
9					6.99	8.00	9.00	9.99
10					8.57	9.80	11.02	12.25
11						11.77	13.25	14.72

TABLE 3

Average taper rate* of 121 felled white spruce trees,

23 to 30 years old

Statistical name	Statistical date, by sections of trees (each tree divided in 10 equal parts) d.o.b.									
	0.00	0.05	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90
Average taper rate of tree ($\bar{x}$)	119.3	109.5	90.3	81.8	73.5	65.0	53.8	41.5	28.6	14.7
Standard error of mean (δm)	0.83	0.42	0.29	0.38	0.41	0.48	0.49	0.49	0.42	0.31
Standard deviation (δ)	9.15	4.59	3.16	4.22	4.52	5.34	5.37	5.43	4.60	3.39
Coefficient of variation W %	7.67	4.19	3.50	5.16	6.15	8.22	9.98	13.07	16.10	23.06
Index of probability ($\delta m/x$) x 100	0.69	0.38	0.32	0.46	0.56	0.74	0.91	1.18	1.47	2.10
Confidence interval Cl. probability level 0.05, D.F. = 120	$\frac{117.6}{120.9}$	$\frac{108.7}{110.3}$	$\frac{89.7}{90.9}$	$\frac{81.0}{82.5}$	$\frac{72.7}{74.3}$	$\frac{64.0}{65.9}$	$\frac{52.8}{54.8}$	$\frac{40.5}{42.5}$	$\frac{27.8}{29.4}$	$\frac{14.1}{15.3}$
Maximum permissible limit or error %	1.4	0.7	0.6	0.9	1.1	1.5	1.8	2.3	2.9	4.2
Form index or form quotient $qn/_{0,1}$	1.19	1.09	0.90	0.82	0.73	0.65	0.54	0.41	0.29	0.15
Paraboloid taper rate	$d_{0,0}$	$d_{0,1}$	$d_{0,2}$	$d_{0,3}$	$d_{0,4}$	$d_{0,5}$	$d_{0,6}$	$d_{0,7}$	$d_{0,8}$	$d_{0,9}$
	105.0	100.0	94.0	88.0	81.5	74.3	66.5	57.5	47.0	33.0

* Average taper rate is calculated as a function of diameter taken at 1/10 of the tree height ($d_{0,1}$). This diameter is given a value of 100, and the other diameters estimated, depending on their value on $d_{0,1}$. Thus, if the diameter of a tree at 10% of its height is 5.6 inch ($d_{0,1}$), then at $d_{0,0}$ it is estimated to be 6.7 inch and at $d_{0,9}$, 0.8 inch.

TABLE 4

Relation between average and estimated volume

d.b.h. class inches	Real average vol. formula (8) ft^3	Confidence: interval (P = 0.05)	Est. vol. formula (25) ft^3	Deviations in %
2	0.315	0.268 - 0.362	0.321	+ 1.9
3	0.662	0.561 - 0.763	0.675	+ 2.0
4	1.348	1.199 - 1.497	1.340	- 0.6
5	2.341	2.103 - 2.579	2.378	+ 1.6
6	3.644	3.251 - 4.037	3.706	+ 1.7
7	5.557	5.300 - 5.813	5.480	- 1.4
8	7.351	6.594 - 8.108	7.265	- 1.2
9	8.821	8.032 - 9.610	8.757	- 0.7
10	11.041	9.880 -12.202	11.018	- 0.2

TABLE 5

Comparison of estimation between Table 2, and Honer's and Berry's volume tables in ft^3 per acre of six sample plots from white spruce plantations at Drummondville

Volume tables	Sample plots					
	7	8	13-14	17	18	21-22
Berry (plantation)	1902	2616	944	1571	1396	884
Honer (natural)	2308	2647	976	1641	1456	912
Popovich (plantation)	2318	2689	902	1613	1435	964