Research paper

Stand Volume Equation Developed from an Experimental Form Factor with the Breast Height Form Quotient

Lei Kong,[1)] Hua Yang,[1,2)] Xin-Gang Kang,[1)] Xian-Yu Meng,[1)] Jia-Li Xie[1)]

【Summary】

The experimental form factor (EFF) is the ratio of tree volume to the volume of a cylinder that has the same diameter at breast height and is 3 m (K) higher than the tree, which is an important method to estimate stand volume. To estimate the stand volume more accurately and simply, the proposed approach considered form factors. Based on 14 clear-cut sample plots of spruce-fir mixed stands at Changbai Mountains, Jilin, China, an EFF stand volume formula was established using mathematical deduction and was weighed against the estimating precision by a 2-entry table method. The results demonstrated that the model had a smaller deviation, and better prediction precision and goodness of fit by applying the EFF formula than the 2-entry table formula. Through an independent-samples *t*-test and *F* test, no significant differences were observed between the real stand volume and the stand volume estimated by the EFF formula. The EFF volume formula was first deduced from the theoretical stem curve formula with the breast height form quotient (BFQ). In a comparison of results obtained by the classical approach, EFF values for 11 species applying the theoretical derivation marginally differed. The EFF was verified to be affected only by species. Item K was certified to be constant term with a coefficient of variance of 0.02.

Key words: experimental form factor, breast height form quotient, stand volume, height class.

Kong L, Yang H, Kang XG, Meng XY, Xie JL. 2012. Stand volume equation developed from an experimental form factor with the breast height form quotient. Taiwan J For Sci 27(4):357-67.

[1)] Key Laboratory for Silviculture and Conservation Ministry of Education, Beijing Forestry Univ., Po Box 452, 35 Tsing Hua Eastern Rd., Beijing 100083, China. 北京林業大學省部共建森林培育與保護教育部重點實驗室，100083北京市清華東路35號信箱452，中國。

[2)] Corresponding author, e-mail:huayang@bjfu.edu.cn 通訊作者。

Received June 2012, Accepted October 2012. 2012年6月送審 2012年10月通過。

研究報告

基於樹種胸高形率的實驗形數法推算林分蓄積量研究

孔雷[1)] 楊華[1,2)] 亢新剛[1)] 孟憲宇[1)] 謝佳利[1)]

摘 要

實驗形數是樹高材積與樹高加3(K項)乘以胸高斷面積的比值。實驗形數法是基於各樹種平均實驗形數來估算林分蓄積的重要方法。實驗形數法考慮了林木形狀，使得估算林分蓄積更準確簡易。試驗地位於中國吉林省長白山區天然雲冷杉混交林14塊皆伐標準地，建立了該地區的實驗形數林分蓄積方程，並且與該地區二元材積表估計林分蓄積的精度進行比較。結果顯示：相較於二元材積表，實驗形數林分蓄積方程有更小的平方差，更高的預估精度和擬合度。通過T檢驗和F檢驗，實驗形數林分蓄積方程估算值與分析解析木樣地蓄積值很接近，在統計上無顯著差異。本文第一次從樹種胸高形率和樹幹曲線方程理論推倒出實驗形數方程。與經典經驗實驗形數算法相比，本文推算11個樹種的實驗形數差別不大。實驗形數也第一次被證明只受到不同樹種的影響，常數項K平均積為3.3(變異係數為0.02)。

關鍵詞：實驗形數、胸高形率、林分蓄積、樹高級。

孔雷、楊華、亢新剛、孟憲宇、謝佳利。2012。基於樹種胸高形率的實驗形數法推算林分蓄積量研究。台灣林業科學27(4):357-67。

INTRODUCTION

Estimating stand volume is a basic requirement for practical forest management and also growth and biomass research. This requires the methods used be accurate and practical under field conditions. Due to the influence of the form of the stem profile for each species, tree and stand volume estimations considering their geometry are becoming increasingly important (Socha 2007). The form factor method is an effective way to resolve this problem. A form factor is the ratio of tree volume to the volume of a geometrical solid, such as a cylinder, cone, or cone frustum that has the same diameter and height as the tree (Benbrahim and Gavaland 2003). A large number of factors including the species, provenance, climate, tree age, and stand density affect the stem form and thus the estimation of stand volume (Benbrahim and Gavaland 2003, Socha and Kulej 2007). The use of different reference points has resulted in many different types of form factors. Four of these factors are particularly important due to their popularity, namely the absolute form factor (Claughton-Wallin and McVicker 1920), the breast height form factor (Inoue 2006), the true form factor (Socha and Kulej 2005) and the normal form factor (Kajihara 1969).

The stem form and factors are widely used for the tree level, which describes the decrease of the over-bark or under-bark stem diameter with increasing height above the base. Several methods have been proposed to access the generality of stem volume estimation and stem form. The usual method to estimate the individual volume of a standing tree is to use stem profile equations (Ter-Mikaelian et al. 2004). Taper functions are also widely used in forestry to evaluate diameters at any point on the stem and thus calculate a total stem volume or merchantable volume at any top diameter (Brooks et al. 2007, Kurinobu et al. 2007). Predicting the percent volume by pieces is another method for estimating the board foot volume of standing trees. Mesavage and Girard form class volume tables are wildly used in eastern and southern US, even though newer, more sophisticated volume functions are available (Rothacher 1948). So far, few studies have investigated the quantification of current and eventual stand-level volumes on the variation in stem form (Inoue 2006), although estimating stand volume with a form factor is more accurate. Because the form factor for the species of interest must be measured from felled sample trees, which causes prohibitively high costs. Moreover, these popular form factor values significantly vary among different trees for a species of interest. Usually, the stand volume is quantified from the diameter and height of a mean tree, and sometimes for each diameter class separately. Two-entry tree volume tables are most commonly used to evaluate the stand volume for specified diameter and height strata, and the corresponding volume functions take diameter at breast height (dbh) and height as predictor variables. However, the presumption is that the form factor of a species, for a given dbh and height, is not influenced by external factors, such as the provenance, site, or stand treatment. Volume estimation with form height has a moderate advantage over the 2-entry tree volume table, as height measurements are restricted to the subpopulation of trees around the basal area central tree (Van Laar and Akça 2007). However, there is also greatly unsustainable variations in form height values in various trees for a species. Therefore, an uncomplicated, slightly varying or fixed form factor needs to be invented to quantify stand volumes. Based on 13,084 sample trees of Chinese fir in 6 provinces of China (including 4877 seeding trees and 8207 cut wood), logging volume tables of the Soviet Union in 1931, pine tree volume tables of Germany in 1930, a tree height form factor table of Japan, and a pine tree form table from the New York, USA, Lin (1964) proposed a way to calculate the stand volume called the experimental form factor (EFF) method. It takes into account the correlation between the form factor and stand volume, and has improved accuracy for evaluating the stand volume. As an index to describe the stem form, the EFF method is based on 2 advantages: (1) the varying range of the EFF in a stand has no significant difference with that of the entire country; and (2) there is no significant difference between the range of variation in the EFF in a specific diameter group or height group and that of the entire spectrum. The EFF has been an effective measure for estimating the volume of a stand. However, it is just an empirical formula, and has not been proven by existing mathematical approaches.

The goal of this study was to further develop the research of Lin (1964) and develop a theoretical method to verify the EFF empirical formula and evaluate the stand volume of different species with the EFF. Respective objectives were to: (1) provide a theoretical method to estimate the EFF for different tree species; (2) verify that item K is close to a constant; and (3) assess the accuracy of calculating the stand volume using the EFF method.

MATERIAL AND METHODS

Data

The study data were collected from 14 clear-cut sample plots at the Jingouling Experimental Forest Farm (130°5′~130°20′E, 43°17′~43°25′N), Wangqing Forestry Bureau, Jilin Province. The elevation, slope, slope position, and slope aspect of each sample plot were recorded. The regional vegetation type was a mixed broadleaf Korean pine (*Pinus koraiensis*) forest. Due to disturbances and management practices, however, the primary forest had shifted to spruce-fir-dominated mixed coniferous forests. The main tree species are Yedo spruce (*Picea jezoensis* var. *microsperma* (Lindl) Cheng et L.K.Fu) and Manchurian fir (*Abies nephrolepis* (Trautv) Maxim). Other tree species composing the stands include Korean pine, Amur linden (*Tilia amurensis*), Asian white birch (*Betula platyphylla*), ribbed birch (*B. costata*), Changbai larch (*Larix olgensis*), Mono maple (*Acer mono*), Manchurian ash (Fraxinus mandshurica), Ussuri popular (*Populus ussuriensis*), and elm (*Ulmus propinqua*).

Real stand volume

Sample plots were 50×50 m in size. The location of all of the 2793 sample trees with a diameter at breast height (dbh) of ≥ 5 cm were mapped, dbh, height, height to the lowest dead branch, and crown width were measured, and then all were cut during 1987 and 1989, and subjected to a tree-ring analysis. After the trees were cut, the diameters were measured at ¼, ½, and ¾ of the tree height to calculate the breast height from quotient (q_i) for a tree ($q_i = \frac{di_{1/2}}{di_{1.3}}$); where $di_{1/2}$ is the diameter of at 1/2 height of tree i, and $di_{1.3}$ is the diameter of at 1/3 height of tree i). Subsequently, stem disks taken at 2-m intervals from the basis were used to estimate volumes of the trees for each species in this stand, the entire real stand volumes were quantified by the sum total of all species.

Stand volume equation

We used the stem curve function by Forslund (1982):

$$y^2 = PX^r; \quad (1)$$

where y is the cross-section radius, P is a coefficient, X is the length from the top to the cross-section, and r is a form exponent. In view of the fact that the relative position at breast height varies under different tree heights, the stem curve function was modified to:

$$y^2 = P(H_x)^r; \quad (2)$$

where H_x is the distance from the top to x height, so the basal area at breast height can be expressed as:

$$g_{1.3} = \pi P(H - 1.3)^r. \quad (3)$$

Here, $g_{1.3}$ is the basal area at breast height; and H is the average tree height. The combination of equations (2) and (3) produces the tree volume formula:

$$\bar{V} = \int_0^H \pi y^2 dx = \pi p \int_0^H (H_x)^r dx$$
$$= \frac{\pi p}{r+1}(H)^{r+1} = \frac{1}{r+1}(H)^{r+1}\frac{g_{1.3}}{(H - 1.3)^r}$$
$$= \frac{1}{r+1}\left(\frac{H}{H - 1.3}\right)^{r+1}(H - 1.3)g_{1.3}. \quad (4)$$

The former part of result of equation (4) can be expressed below, as long as $\frac{1.3}{H - 1.3} < 1$

$$f_{1.3} = \frac{1}{r+1}\left(\frac{H}{H - 1.3}\right)^{r+1} = \frac{1}{r+1}\left(1+\frac{1.3}{H - 1.3}\right)^{r+1}$$
$$= \frac{1}{r+1}\left[1+(r+1)\frac{1.3}{H - 1.3}+\frac{(r+1)r}{2}\left(\frac{1.3}{H - 1.3}\right)^2 +\cdots+\left(\frac{1.3}{H - 1.3}\right)^{r+1}\right]$$
$$\approx \frac{1}{r+1}\left[1+\frac{1.3(r+1)}{H - 1.3}+\frac{1.3}{H - 1.3}\right]. \quad (5)$$

Integration of equation (4) results in:

$$\bar{V} = \frac{1}{r+1}\left[1+\frac{1.3(r+2)}{H - 1.3}\right](H - 1.3)g_{1.3}$$
$$= \frac{1}{r+1}[(H - 1.3)+1.3(r+2)]g_{1.3}$$
$$= \frac{1}{r+1}[H+1.3(r+1)]g_{1.3}. \quad (6)$$

In addition, the relationship between r and q can be expressed by the empirical equation (Suzuki 1943):

$$r+1=\frac{3\pi Q}{4q}; \tag{7}$$

where Q represents the mean BFQ of all the conifer and broadleaf species for the entire area, and q is the mean BFQ of a species.

$$q=\frac{1}{n}\sum_{i=1}^{n}\frac{di_{1/2}}{di_{1.3}}; \tag{8}$$

where $di_{1/2}$ and $di_{1.3}$ are respectively the diameter at 1/2 height and breast height of the i_{th} tree of a species. Because of slight fluctuations in the EFF value and BEQ value among different height classes for species of interest as shown in Figs. 1 and 2, equation (7) can be incorporated into equation (6):

$$V=\frac{4q}{3\pi Q}[H+1.3\frac{3\pi Q}{4q}]g_{1.3}. \tag{9}$$

Mean form quotient and mean height

The mean BFQ (Q) of all conifer and broadleaf species is an approximate number calculated using the following formule and data from Table 2:

$$Q=\frac{\sum_{i=1}^{n} q_i}{n} \text{ and} \tag{10}$$

$$H=\frac{\sum_{i=1}^{n}H_iG_i}{\sum_{i=1}^{n}G_i}; \tag{11}$$

where H is the mean tree height of a certain species, H_i is the tree height of a certain species

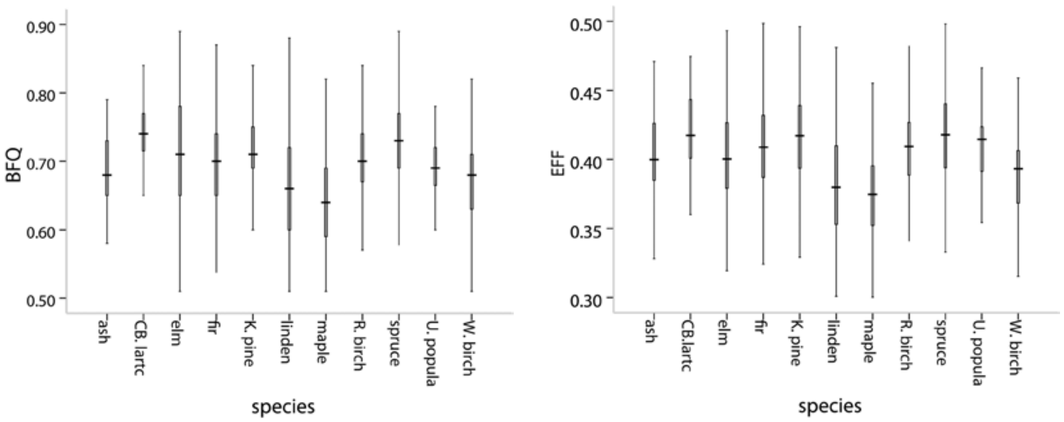

Fig. 1. Mean breast height form quotient (BFQ) and experimental form factor (EFF) among different species. Species are defined in Table 2.

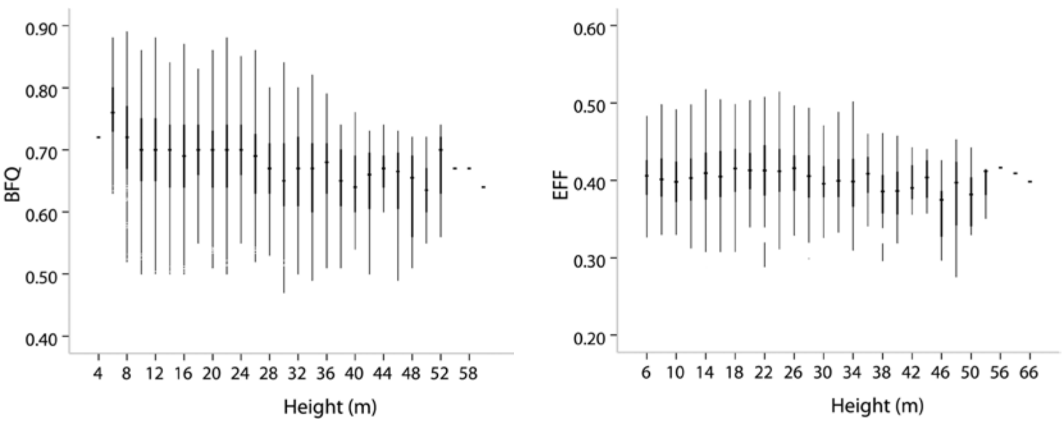

Fig. 2. Variation of the mean breast height form quotient (BFQ) and experimental form factor (EFF) at different tree heights.

in each dbh class, and G_i is the basal area of the DBH class. The mean BFQ of all conifer and broadleaf species (Q) was estimated to be 0.734. Substituting 0.734 for Q in equation (9), the following equation was obtained:

$$\bar{V} = (0.578q)[H + \frac{2.248}{q}]g_{1.3}; \quad (12)$$

where $0.578q$ corresponds to an EFF (f_ε) and $\frac{2.248}{q}$ corresponds to K, which means that

$$f_\varepsilon = 0.578q \text{ and} \quad (13)$$

$$K = \frac{2.248}{q}. \quad (14)$$

Equations (10) and (11) suggest that species-specific EFFs can easily be determined when the mean BFQ is given.

Test equation

By comparison to 14 measured stand volumes, the precision of the model was tested using the absolute deviation, relative deviation, absolute mean deviation, and mean relative deviation. The prediction precision was used to test the prediction ability of the model. The Akaike information criterion (AIC) and determination coefficient were

Table 1. General information of 14 clear-cut plots

Plot	Tree species composition	Age (yr)	Mean dbh (cm)	Mean height (m)	No. of trees	Base area (m^2)	Volume/ ha (m^3)
1	5 fir, 1 spruce, 1 linden, 1 K. pine, 1 maple, 1 elm	79	33.8	22.5	792	29.1	253.4
2	3 spruce, 3 fir, 1 R. birch, 1 K. pine, 1 maple, 1 U. popular	84	20.6	13.7	724	25.1	217.9
3	4 fir, 4 K. pine, 1 U. popular, 1 maple	81	29.0	17.7	452	24.6	202.0
4	3 K. pine, 2 fir, 1 spruce, 1 maple, 1 R. birch, 1 linden, 1 elm	58	14.9	10.7	724	24.0	184.1
5	3 spruce, 2 fir, 2 K. pine, 1 maple, 1 linden, 1 R. birch	96	30.4	16.8	392	21.1	169.1
6	3 spruce, 2 R. birch, 1 linden, 1 maple, 1 K. pine, 1 fir, 1 elm	44	15.8	16.2	556	21.4	182.2
7	4 spruce, 3 fir, 1 R. birch, 1 K. pine, 1 linden	65	17.4	12.7	912	24.8	190.9
8	3 fir, 3 spruce, 2 K. pine, 1 maple, 1 linden	68	16.5	12.3	1228	33.8	262.6
9	3 linden, 2 K. pine, 1 fir, 1 maple, 1 spruce, 1 W. birch, 1 R. birch	59	15.3	11.5	956	26.2	194.8
10	4 fir, 2 spruce, 1 K. pine, 1 maple, 1 linden, 1 R. birch	93	24.3	16.0	596	22.5	178.0
11	2 fir, 2 spruce, 1 K. pine, 1 linden, 1 R. birch, 1 maple 1 W. birch, 1elm	55	13.3	12.2	1140	24.1	169.1
12	5 spruce, 2 fir, 1 K. pine, 1 linden, 1 maple	44	15.1	12.2	856	23.6	175.2
13	3 spruce, 3 fir, 3 K. pine, 1 linden	43	13.4	11.8	804	21.8	161.6
14	4 fir, 4 spruce, 1 K. pine, 1 linden	64	14.5	13.1	1292	35.8	325.1

dbh, diameter at breast height.
Tree species are defined in Table 2.

used to estimate the complexity of the model and the degree of fit:

$$d_i = \sum_{i=1}^{n} \frac{y_i - \hat{y}_i}{n}, \quad (15)$$

$$\bar{d}_i = \sum_{i=1}^{n} \left| \frac{y_i - \hat{y}_i}{n} \right|, \quad (16)$$

$$S_{af} = \frac{1}{n} \sum_{i=1}^{n} \left[\frac{y_i - \hat{y}_i}{n} \right] \times 100\%, \quad (17)$$

$$S_{rf} = \frac{1}{n} \sum_{i=1}^{n} \left| \frac{y_i - \hat{y}_i}{n} \right| \times 100\%, \quad (18)$$

$$P = 1 - \frac{t_\alpha \sqrt{\sum_{i=1}^{n} (y_i - \hat{y}_i)^2}}{\bar{y}_i \sqrt{n(n - m)}}, \quad (19)$$

$$R^2 = 1 - \frac{\sum_{i=1}^{n} (y_i - \hat{y}_i)^2}{\sum_{i=1}^{n} (y_i - \bar{\hat{y}}_i)^2}, \text{ and} \quad (20)$$

$$AIC = 2n\ln\left(\frac{RSS}{n}\right) + n\ln(2\pi) + n + tr(S); \quad (21)$$

where d_i is the absolute deviation, $\bar{d}_i$ is the mean deviation, S_{af} is the absolute mean deviation, S_{rf} is the average relative deviation, P is the prediction precision, R^2 is the determination coefficient, y_i is the measured value, $\hat{y}_i$ is the predicted value, n is the number of samples, m is the number of variables, $\frac{RSS}{n}$ is the estimated standard error of the error term, and tr(S) denotes the trace of the hat matrix.

RESULTS

EFF, BFQ, and K among different species

According to Table 2, the mean BFQ of each species ranged 0.62~0.73. Item K was proven to be a constant term for a species (coefficient of variance = 0.02), which was calculated on the basis of different mean BFQ and EFF values for the species of interest, and partial results are shown in Table 2.

EFF and BFQ of different species

Variances of the EFF determined for the different species were slight. The figure showed that mean variances ranged from 0.4 for linden to 0.46 for Changbai larch and did not significantly differ. Meanwhile, the mean BFQ of different species under comparison ranged on average from 0.65 for linden to 0.73 for spruce as shown in Fig. 1. On the basis of the analysis of variance, significant differences were found in the mean values of the BFQ derived from different species. Therefore, variances of the EFF were more stable.

EFF and BFQ of different height classes

Figure 2 shows values of the EFF and BFQ at different heights. It indicates that the

Table 2. Breast height form quotient, no. of trees, experimental form factor (EFF) (theoretical derivation), and K from different species

Species	Breast form quotient (q)	No. of trees (n)	EFF (f_ε)	K
W. birch (*Betula platyphylla*)	0.65	45	0.39	3.46
Linden (*Tilia amurensis*)	0.65	338	0.38	3.53
R. birch (*Betula costata*)	0.69	239	0.41	3.27
K. pine (*Pinus koraiensis*)	0.72	302	0.42	3.15
Fir (*Abies nephrolepis*)	0.68	599	0.41	3.29
CB. larch (*Larix olgensis*)	0.75	23	0.42	3.04
Maple (*Acer mono*)	0.62	211	0.41	3.67
Ash (*Fraxinus mandshurica*)	0.69	35	0.37	3.31
U. popular (*Populus ussuriensis*)	0.69	66	0.40	3.28
Elm (*Ulmus propinqua*)	0.68	72	0.40	3.34
Spruce (*Picea jezoensis*)	0.73	595	0.43	3.12

BFQ was influenced both by the stem form and height. The distribution of the BFQ was affected by variations in the stem form and height. However, the EFF was only impacted by the stem form of a species, but not height, because its distribution reflected variations in the stem form. So the variation of the EFF at different tree heights was also more stable than the BFQ. There was a strong relationship between the shape of the stem and the abilities to tolerate low light levels. The stronger abilities a tree had, the fuller shape the stem was. Because most coniferous trees were tolerant species, shapes of stems of coniferous trees were closer to a cylinder than those of broadleaf trees.

Use of the model

Compared to the 2-entry volume table, the results of calculating the stand volume using the EFF showed better predictive precision overall. What was more important, was that it had a small deviation. Its mean deviation was 0.46, and its absolute deviation was 1.34. The mean absolute deviation of the calculation results by this method from the real stand volume data was 1%. The average relative deviation was 3%. The AIC was 24.1. The determination coefficient (R^2) of the model was 0.97. Therefore, the model provided a better fit to the data from the real stand volume as shown in Table 3.

DISCUSSION AND CONCLUSIONS

Item K

Good accuracy in volume prediction was achieved using the EFF calculated from equation (13). Based on the mean BFQ data of all species, item K was proven to be close to a constant item (CV = 0.02). When item K was bigger, the EFF was smaller in equation (12). Consequently, the bias was offset to a certain extent, and a more accurate result was obtained. The error of equation (12) may have resulted from 2 sources: first, the data for testing were insufficient; and second, in equation (5), $f_{1.3}$ is an approximation of the first 2 terms in the series expansion by omitting other terms. Suzuki (1943) used the standing volume method to estimate a fir tree volume formula using the following equation, $V = (1+\frac{H}{3})D_{1.3}^2$, e.i. $V = \frac{4}{3\pi}(3+H)g_{1.3}$. It is a special case of the EFF volume equation, the Q of which is equal to the BFQ of a species.

Relationships among region, height, and the EFF

The EFF is characterized by virtue of a normal form factor, which is not affected by height and possesses the advantage of the breast height form factor being convenient to utilize. After the EFF was proposed, the relationship between the height and EFF was discussed for a long time. Some researchers expressed opposing opinions, suggesting that the varying range of experimental stem forms of trees with the same dbh and height is smaller than that of trees with different dbh and height values (Hua and Xu 1965, Tang et al. 2007). However, according to equation (5), $f_{1.3}$ depends on r and the tree height, whereas the EFF is a coefficient ($f_\varepsilon = 4q/3\pi Q$), which is not greatly or slightly influenced by tree height.

Although this paper does not provide enough studies to consider the part due to restricted data of sample trees, Lin (1964) finished a great amount of research centralizing EFF value fluctuations, and proposed that mean EFF values of Scotch pine, spruce, and Chinese fir were almost the same between the Soviet Union and China. Studies also confirmed the conclusion that a fixed EFF for a species is able to be utilized in stand volume quantification for the whole country and across different countries (Tables 4, 5). However, to some extent, the mean EFF of sample trees for a species appears to be discrepant in a village or even a small forest farm. Nevertheless, as the number of sample units increases, the mean EFF of sample tree variation becomes more and more stable and close to a fixed value. Consequently, the assumption is that applying the EFF approach must be based on a large area, a town at least. The results show that the CV of the EFF for a certain town is generally smaller than 3%, or 5% for special cases.

Table 3. Statistical features of different stand volumes for 14 plots by the experimental form factor (V_{eff}) and 2-entry volume table (V_T)

Plot	n	Statistics				AIC	R^2	Predictive precision
		d_i	$\bar{d}_i$	S_{rf}	S_{af}			
V_{eff}-V	14	0.46	1.34	1%	3%	24.1	0.97	0.98
V_T-V	14	-3.29	3.75	-8%	8%	48.9	0.86	0.95

AIC, Akaike information criterion.

Table 4. Experimental form factor (EFF) values of the tree species in China, the US, the Soviet Union, Germany, and Japan (Lin 1964)

Stem form grade	Forest type	EFF	Species
I	coniferous trees	0.45	*Pinus yunnanensis faranch*, *Abies nephrolepis*
II		0.43	*Cunninghamia lanceolata* (Lamb) Hook, *Picea jezoensis*
III		0.42	*Pinus koraiensis*, *Pinus armandii* Franch, *Pseudotsuga sinensis* Dode
IV		0.41	*Picea schrenkiana* Fisch.et Mey, *Cryptomeria* fortunei Hooibrenk ex Otto et Dietr, *Larix gmelinii* (Rupr.) Rupr, *Larix sibirica* Ledeb, *Pinus sylvestris* L. var. *mongolica* Litv, *Pinus densiflora* Sieb. et Zucc, *Pinus thunbergii* Parl, *Keteleeria davidiana* (Bertr.) Beissn
V	broadleaf trees	0.40	*Populus ussuriensis*, *Betula platyphylla*, *Betula costata*, *Acer mono*, *Fraxinus mandshurica*, *Ulmus propinqua*, *Quercus mongolica* Fisch. ex Ledeb, *Cyclobalanopsis glauca* (Thunb.) Oerst, *Robinia pseudoacacia* L.
VI	coniferous trees	0.39	*Pinus massoniana* Lamb

Table 5. Variations in the experimental form factor (f_ε) for Chinese fir in the entire country including Anhui, Hunan, Jiangxi, Fujian, Guangxi, and Guizhou Provinces of China (Lin 1964)

Item	The whole country										Total no. of sample trees	Mean f_ε	CV
EFF	0.29	0.32	0.35	0.38	0.41	0.44	0.47	0.5	0.53	0.56		0.418	0.088
No. of tree samples	22	146	801	2501	4236	3405	1509	404	55	5	13,084		

CV, coefficient of variation.

Advantages of the classical method

By applying the classical method, the EFF formula was developed from the empirical relation (Lin 1964):

$$\frac{g_n}{g_{1.3}} = a + \frac{b}{h}; \qquad (22)$$

where h is the relative height, g_n is the basal area at a relative height of h, and $g_{1.3}$ is the basal area at a height of 1.3 m. This indicates that g_n is inversely proportional to h, when $g_{1.3}$ is fixed. Based on the definition of a normal form factor, the tree volume can be expressed as:

$$V = g_n h f_n = g_{1.3}\left(a + \frac{b}{h}\right) h f_n = g_{1.3}\left(h + \frac{b}{a}\right) a f_n; \quad (23)$$

where f_n is the form factor at a relative height of h. Setting $K = \frac{b}{a}$, $f_\varepsilon = af_n$, using measured parameter h, $g_{1.3}$ and $1.3h/20$ data, formula (23) becomes

$$\bar{V} = f_\varepsilon (H+3) g_{1.3}; \qquad (24)$$

where f_ε is defined as the EFF, which ranges from 0.39 to 0.45 according to different species. After mean f_ε values for individual species are calculated, they can be used in calculating the volume of a stand as follows:

$$M = f_\varepsilon (H_D+3) g_{1.3}; \qquad (25)$$

where M is the volume of plot, $g_{1.3}$ is the total basal area at breast height, H_D is the average height, and f_ε is the EFF. In equation (22), g_n is always represented by the basal area at a relative height of 1/20, and in most cases, 1/20 of the tree height is close to 1.3 m. Although studies proved that equation (22) was viable as the curve equation of the bole section between 1/20 of the height and 1.3 m, it cannot describe the variances of different sections more exactly, like $y = a+bx$ or $y = a+bx+x^2$. In contrast, volume formula (12) is more reasonable as it was developed from equation (2) which describes different kinds of bole profiles. The effect is satisfactory when the volume is calculated using the mean EFF, and this method does not belong to the method of the form class volume table, but a method of a standard volume table. It is more like a method of the mean form factor, standard table, or standard volume table.

Assessment of the stand volume equation

According to Lin (1964), many scholars suggested that the dbh form factor is stable with a small CV (CV ≤ 8%) in their studies. In particular, they concluded that a specific species has almost the same mean form quotient regardless of whether it is in a stand or a larger area. The BFQ is not reflected in equation (24), but its role is directly shown in equation (12). It is acceptable to consider equations (12) and (24) as "a simplified method of a form class volume table". No significant difference between the real stand volume and stand volume estimated by the EFF formula indicates that the EFF stand volume has a better goodness of fit and predictive ability. The EFF is proposed on the basis of studying a large quantity of samples of various species from different countries in different dbh classes and height classes. The average EFF can be conveniently qualified to estimate forest volumes in different regions, and it is not necessary to establish a form class volume table of certain species in a particular region.

ACKNOWLEDGEMENTS

This research was supported by the National Forestry Public Welfare Foundation (200804027) and the "Eleventh" Major Scientific and Technical Foundation (2006BA-D03A08-04).

LITERATURE CITED

Benbrahim M, Gavaland A. 2003. A new stem taper function for short-rotation poplar.

Scan J For Res 18:377-83.

Brooks JR, Jiang L, Clark A. 2007. Compatible stem taper, volume, and weight equations for young longleaf pine plantations in southwest Georgia. South J Appl For 31:187-91.

Claughton-Wallin H, McVicker F. 1920. The Jonson "absolute form quotient" as an expression of taper. J For 18:346-57.

Hua WK, Xu GH. 1965. Some suppose for "measurement techniques for standing trees developed from stem form factors". Sci Sil Sin 2:188-92.

Inoue A. 2006. A model for the relationship between form-factors for stem volume and those for stem surface area in coniferous species. J For Res 11:289-94.

Kajihara M. 1969. Estimation of normal form factor and its application to the measurement of stand volume. J Jpn For Soc 51:49-56. [in Japanese with English summary].

Forslund RR. 1982. A geometrical tree volume model based on the location of the centre of gravity of the bole. Can J For Res 12(2): 215-21.

Kurinobu S, Prehatin D, Mohanmad N, Matsune K. 2007. A stem taper equation compatible to volume equation for *Paraserianthes falcataria* in Pare, East Java, Indonesia: its implications for the plantation management. J For Res 12:473-8.

Lin CG. 1964. Measurement techniques for standing trees developed from stem form factors. Sci Sil Sin 2:188-92.

Rothacher JS. 1948. Percentage distribution of tree volume by logs. J For 46:115-8.

Socha J. 2007. Estimation of the effect of stand density on Scots pine stem form. Acta Sci Pol 6:59-70.

Socha J, Kulej M. 2005. Provenance-dependent variability of *Abies grandis* stem form under mountain conditions of Beskid Sądecki (southern Poland). Can J For Res 35:2539-52.

Socha J, Kulej M. 2007. Variation of the tree form factor and taper in European larch of Polish provenances tested under conditions of the Beskid Sądecki mountain range (southern Poland). J For Sci 12:538-47.

Suzuki G. 1943. Forest mensuration. Tokyo, Japan: kosho.or.jp. p 250-8. [in Japanese].

Tang W, Tan XQ, Wang SD. 2007. Studies on the variation of the experimental form factor of Chinese fir single tree in Sichuan. Sichuan For Exp Desi 2:13-7.

Ter-Mikaelian MT, Zakrzewski WT, MacDonald GB, Weingartner DH. 2004. Stem profile equations for young trembling aspen in northern Ontario. Ann For Sci 61:109-15.

Van Laar A, Akça A. 2007. Forest mensuration. Dordrecht, Netherlands: Springer. p 128-34.