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Evaluation of Some Stem Taper Models for *Camellia japonica* in Mount Halla, Korea

Sung Cheol JUNG[1] http://orcid.org/0000-0002-8337-917X; e-mail: scjung@forest.go.kr

Yeon Ok SEO[1] http://orcid.org/0000-0003-2444-1807; e-mail: yoseo85@gmail.com

Hyun Kyu WON[1] http://orcid.org/0000-0003-3811-8373; e-mail: hkwon@forest.go.kr

Roscinto Ian C. LUMBRES[1,2] http://orcid.org/0000-0003-4221-6435; e-mail: rosslumbres@yahoo.com

1 *Warm Temperate and Subtropical Forest Research Center, Korea Forest Research Institute, Seogwipo, Seogwipo city, Jeju, 679-050, Korea*

2 *College of Forestry, Benguet State University, La Trinidad, Benguet, 2601, Philippines*

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Abstract: This study was conducted to evaluate the performance of the four stem taper models on *Camellia japonica* in Jeju Island, Korea using fit statistics and lack-of-fit statistics. The five statistical criteria that were used in this study were standard error of estimate (*SEE*), mean bias ($\overline{E}$), absolute mean difference (*AMD*), coefficient of determination (R^2), and root mean square error (*RMSE*). Results showed that the Kozak model 02 stem taper had the best performance in all fit statistics (*SEE*: 3.4708, $\overline{E}$: 0.0040 cm, *AMD* : 0.9060 cm, R^2 : 0.9870, and *RMSE* : 1.2545). On the other hand, Max and Burkhart stem taper model had the poorest performance in each statistical criterion (*SEE*: 4.2121, $\overline{E}$: 0.2520 cm, *AMD* : 1.1300 cm, R^2 : 0.9805, and *RMSE*: 1.5317). For the lack-of-fit statistics, the Kozak model 02 also provided the best performance having the best *AMD* in most of the relative height classes for diameter outside bark prediction and in most of the DBH classes for total volume prediction while Max and Burkhart had the poorest performance. These stem taper equations could help forest managers to better estimate the diameter outside bark at any given height, merchantable stem volumes and total stem volumes of the standing trees of *Camellia japonica* in the forests of Jeju Island, Korea.

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Introduction

Accurate methods for estimating total and merchantable volumes are important for efficient forest inventory which is essential for sustainable forest management (Fonweban 1999; Hofstad 2005; Akindele and LeMay 2006; Haywood 2009; Guendehou et al. 2012). Models that can estimate stem volume at any height are important in forest growth and yield modeling (Klos et al. 2007) and are considered as prerequisite for a successful forest planning and management (Kublin et al. 2008). Several authors (Figueiredo-Filho et al. 1996; Jiang et al. 2005; Ozcelik et al. 2011; Subedi et al. 2011; Li et al. 2012) stated that stem taper equation is one of the most accurate methods that can predict the stem diameter at any given height and volume of standing trees. Most of the stem taper models use total height, DBH, and height above the ground as predictor variables (Berhe and Arnoldsson 2008) because these are usually measured during forest inventories (Brook et al.

2008).

According to Berhe and Arnoldsson (2008) and Li et al. (2012), the most commonly used stem taper equations could be divided into two major categories. First is the segmented polynomial taper model such as Max and Burkhart (1976) stem taper model, which according to Kozak (1988) uses different sub-functions for various parts of the stem. The second one is the continuous variable exponent or form taper models such as Kozak taper models (Kozak 1988; 2004), wherein it is assumed that the form of the tree changes continuously along the stem (Yang et al. 2009; Li and Weiskittel 2010; Heidarsson and Pukkala 2011; Li et al. 2012). Kozak (2004) explained that stem taper equations are better compared to the conventional volume equations because the former can estimate the stem diameter at any height along the stem, merchantable height to any top diameter and from any stump height, and volume of a stem log at any length and at any height from ground in addition to merchantable stem volume and total stem volume. Moreover, different researches had proven the accuracy and efficiency of stem taper models for the different species in many countries (Figueiredo-Filho et al. 1996; Brooks 2001; Brooks et al. 2002; Lee et al. 2003; Kozak 2004; Jiang et al. 2005; Rojo et al. 2005; Coble and Hilpp 2006; Corral-Rivas et al. 2007; Klos et al. 2007; Berhe and Arnoldsson 2008; Brooks et al. 2008; Son et al. 2009; Li and Weiskittel 2010; Heidarsson and Pukkala 2011; Li et al. 2012). In Korea, the Kozak (1988), Max and Burkhart (1976), and Lee et al. (1999) stem taper equations are the most commonly used taper models that were fitted to the different species. In most studies in this country, the Kozak (1988) model has provided better performance as compared to the two stem taper equations specifically for six major tree species (*Pinus densiflora*, *Pinus rigida*, *Pinus koraiensis*, *Larix kaempferi*, *Quercus accutissima* and *Quercus mongolica*) (Son et al. 2002), and *Quercus acuta* in Jeju Island (Chung et al. 2010).

The Republic of Korea has a total of 5164 ha of experimental forests being managed by the Korea Forest Research Institute (KFRI) and approximately 3053 ha can be found in Jeju Island, the southernmost part of this country (KFRI 2014). The three experimental forests in this island namely, Gotjawal (300 ha), Hannam (1203 ha) and Seogwipo (1550 ha) are classified as subtropical forests (KFRI 2014). One of the most dominant tree species in these forests is the *Camellia japonica*. However, growth and yield model such as stem taper equation has not been developed for *Camellia japonica*. Developing stem taper models for this species could help forest managers to easily determine the stem diameter at any given height and subsequently, the volume of the standing trees of *Camellia japonica*. Thus, the objective of this study was to develop stem taper models for *Camellia japonica* in Jeju Island, Korea and to evaluate the performance of these stem taper models.

1 Materials and Methods

1.1 Study site

Jeju Island is located in the southernmost part of South Korea between 126°08'43" to 126°58'20" E and 33°11'27" to 33°33'50" N (Lee et al. 2009) which according to the Korea Forest Service (2012), has total land area of 184,840 ha and 88,874 ha forest cover. Specifically, the study sites were located in the three experimental forests of Jeju Island (Figure 1). The elevation of Hannam experimental forest ranges from 300-750 m above sea level (a.s.l.) and it was 500-900 m a.s.l. in Seogwipo experimental forests (KFRI 2014). On the other hand, Gotjawal forests are considered one of the most important forests in this island due to its unique ecosystem such as the Dongbaekdongsan wetland, which has been designated as a National Wetland Protected Area by the Ministry of Environment of the Republic of Korea and a Ramsar site (Ramsar Convention on Wetlands 2014). These forests are located in Mount Halla which is the highest mountain in the Republic of Korea. The Mean Annual Temperature (MAT) of this island is 15.40°C. In addition, the minimum MAT is 3.20°C and the maximum MAT is 29.80°C. The Mean Annual Precipitation is 1560.80 mm (Korea Meteorological Administration 2014).

1.2 Stem taper models

A total of 200 *Camellia japonica* trees were measured for DBH (cm) and total height (m) using

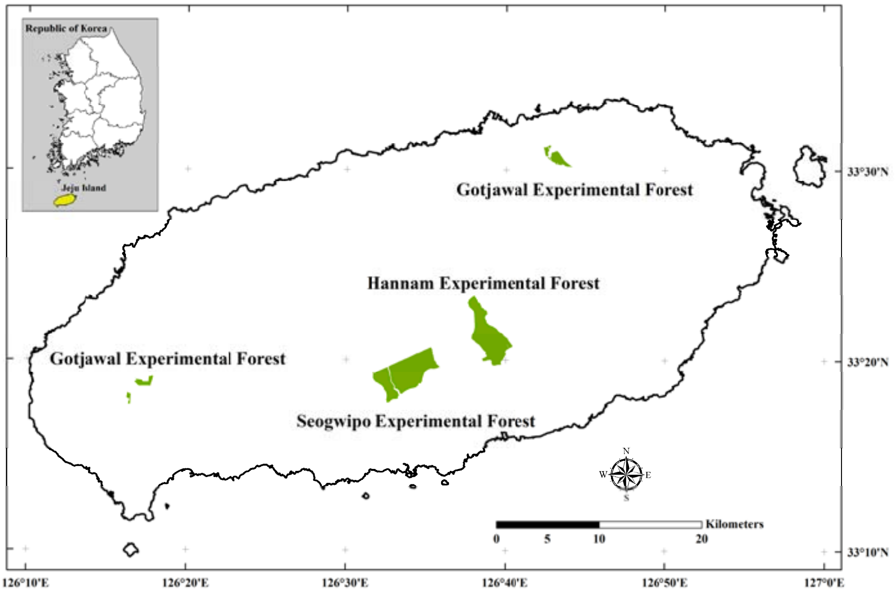

Figure 1 Geographic location of the experimental subtropical forests in Jeju Island, Korea.

standard diameter tape and Haglof Vertex III and Transponder, respectively which represented the different DBH and height classes. To measure the diameter outside bark (DOB, cm) along the stem and their height from the ground (m), the CRITERION RD1000 laser dendrometer instrument was used. DOBs were measured starting from 0.20 m above the ground to the tip of the tree with 1m interval. The mean total height was 8.75 m and the mean DBH was 13.61 cm as shown in Table 1.

The Kozak model 88, Kozak model 01, and Kozak model 02 as presented in Kozak (2004), and MB76 equation (Max and Burkhart 1976) are the four candidate stem taper models that were selected for the estimation of DOB at any given height of *Camellia japonica* in Jeju Island, Korea. The parameters of these models were estimated using the Statistical Analysis System Non-linear (SAS NLIN) procedure (SAS Institute Inc. 2004). One of the limitation of this study is it did not model the serial autocorrelation error structure and this is recommended for future study. The proportional height of the inflection point for *Camellia japonica* in this study was 0.22 which is within the range of the suggested value (0.1-0.3) given by Kozak (2004).

The mathematical forms of these four models are, Kozak model 88:

$$d = a_1 D^{a_2} a_3{}^{D} X^{b_1 Z^2 + b_2 \ln(Z+0.001) + b_3 Z^{1/2} + b_4 e^{Z} + b_5 (D/H)} \quad (1)$$

Table 1 Summary of observed statistics of the data used in the development of stem taper models for *Camellia japonica* in Jeju Island, Korea

Variable	*n*	Mean	Range	SD
Total height m)	200	8.75	5.00-13.50	1.79
DBH (cm)	200	13.61	6.00-29.50	4.52

Notes: SD = Standard deviation and *n* = number of sampled trees.

where: D = DBH (cm), H = tree total height (m), h = height from the ground (m), Z = h/H, proportional height from the ground, d = predicted diameter outside bark at a height from the ground h (cm).

$$X = \frac{(1 - Z^{1/2})}{(1 - p^{1/2})}$$

p = proportional height of the "inflection point", a_i, b_i = estimated parameters

Kozak model 01:

$$d = a_1 D^{a_2} X^{b_1 + b_2 (1/e^{D/H}) + b_3 D^{X} + b_4 X^{D/H}} \quad (2)$$

where: $X = \dfrac{(1 - Z^{1/4})}{(1 - 0.010^{1/4})}$

All other variables were previously defined.

Kozak model 02:

$$d = a_1 D^{a_2} H^{a_3} X^{b_1 Z^4 + b_2 (1/e^{D/H}) + b_3 X^{0.100} + b_4 (1/D) + b_5 H^{Q} + b_6 X} \quad (3)$$

where: $Q=(1-Z^{1/3})$, $X=\frac{Q}{(1-(1.2/H)^{1/3})}$

All other variables were previously defined.

$$\text{MB76: } \frac{d^2}{D^2}=b_1(Z-1)+b_2(Z^2-1)+b_3(a_1-Z)^2 I_1 + b_4(a_2-Z)^2 I_2 \quad (4)$$

$$\text{where: } I_i=\begin{cases}1, & if \quad Z\le a_i \\ 0, & if \quad Z>a_i\end{cases} \quad i=1,2$$

All other variables were previously defined.

1.3 Model evaluation and ranking

This study followed the procedure of Kozak and Kozak (2003) to evaluate model performance. Standard error of estimate (*SEE*), mean bias ($\bar{E}$), and absolute mean difference (*AMD*) were determined to compare the four candidate models. Furthermore, the coefficient of determination (R^2) and root mean square error (*RMSE*) were also used as fit statistics. These were computed as follows:

$$SEE=\sqrt{\frac{\sum_{i=1}^{n}(d_i-\hat{d}_i)^2}{n-k}}$$

$$\bar{E}=\frac{\sum_{i=1}^{n}(d_i-\hat{d}_i)}{n}$$

$$AMD=\frac{\sum_{i=1}^{n}\left|d_i-\hat{d}_i\right|}{n}$$

$$R^2=1-\left[\frac{\sum_{i=1}^{n}(d_i-\hat{d}_i)^2}{\sum_{i=1}^{n}(d_i-\bar{d})^2}\right]$$

$$RMSE=\sqrt{\sum_{i=1}^{n}(d_i-\hat{d}_i)^2/n}$$

where: d_i = observed variable, $\hat{d}_i$ = predicted variable, $\bar{d}$ = observed mean of the variable, k = the number of estimated parameters, and n = number of observation.

Rank analysis was employed to determine the best model. The model that had the lowest value for *SEE*, *RMSE* and *AMD* had the best rank. For R^2, the model that had a value closest to one had the best rank while a value nearest to zero was considered best for $\bar{E}$. The ranks of each model in the five performance criteria were summed and the model with the lowest value was considered the best stem taper model for *Camellia japonica* in Jeju Island, Korea. To determine further which model is most suitable, Kozak and Kozak (2003) recommended using lack-of-fit statistics. In this evaluation, one or more evaluation statistics must be determined for the various subgroups of the independent variable. In this study, *AMD* in the different relative height classes for DOB prediction and in the different DBH classes for total volume prediction were determined for each model.

2 Results and Discussion

The parameters of the four candidate models (Kozak model 88, Kozak model 01, Kozak model 02 and MB76) were estimated and are shown in Table 2. Using five statistical criteria (*SEE*, $\bar{E}$, *AMD*, R^2, and *RMSE*), the performance of these models was evaluated as shown in Table 3. Based on the model evaluation and rank analysis, Kozak model 02 had the best performance, having the best *SEE* (3.4708), $\bar{E}$ (0.0040 cm), *AMD* (0.9060 cm), R^2 (0.9870), and *RMSE* (1.2545). On the other hand, MB76 model had the poorest performance in each

Table 2 Estimated parameter with standard error in parenthesis of the four candidate stem taper models for *Camellia japonica* in Jeju Island, Korea

Model	a_1	a_2	a_3	b_1	b_2	b_3	b_4	b_5	b_6
Kozak 88	1.4432	0.9398	0.9949	-2.2275	0.4177	-1.8152	1.5715	0.0941	
	(0.1134)	(0.0447)	(0.0029)	(0.8985)	(0.2360)	(1.6954)	(0.9636)	(0.0115)	
Kozak 01	3.2237	0.5805		0.7901	-0.7452	-0.1990	1.0034		
	(0.1674)	(0.0210)		(0.0218)	(0.0685)	(0.0122)	(0.0915)		
Kozak 02	1.2055	0.8821	0.0506	-0.2230	-0.1878	1.0858	-2.6459	-0.0128	-0.3294
	(0.0568)	(0.0118)	(0.0230)	(0.0426)	(0.1379)	(0.0301)	(0.4894)	(0.0184)	(0.0545)
MB 76	0.6386	0.0239		0.2393	-0.5291	2.6188	-1695.6		
	(0.0305)	(0.0056)		(0.4054)	(0.2386)	(0.2281)	(2692.1)		

statistical criterion based on the rank analysis (*SEE*: 4.2121, $\overline{E}$: 0.2520 cm, *AMD*: 1.1300 cm, R^2: 0.9805, and *RMSE*: 1.5317). All of the models had positive $\overline{E}$ which indicates that overall, all of the four models under predicted the DOB of *Camellia japonica*. The different biases of the four candidate models were plotted against the relative height to further evaluate the four taper equations (Figure 2) as recommended by Kozak and Kozak (2003). Overall, Kozak model 02 has the best performance followed by Kozak model 01, Kozak model 88, and MB76 based on the different model evaluations and ranking analysis. This result is consistent with the study of Lee et al. (2003), which showed that variable-exponent taper equations had a better estimate of stem diameter than the segmented taper equation.

Table 3 Fit statistics of the different fitted stem taper models for *Camellia japonica* in Jeju Island, Korea

Model	*SEE*	$\overline{E}$	*AMD*	R^2	*RMSE*	Rank
Kozak 88	3.6547	0.0300	0.9740	0.9855	1.3240	3
Kozak 01	3.6021	0.0210	0.9590	0.9858	1.3108	2
Kozak 02	3.4708	0.0040	0.9060	0.9870	1.2545	1
MB 76	4.2121	0.2520	1.1300	0.9805	1.5317	4

For the lack-of-fit statistics, the *AMD* of the four models in different relative height classes (with 0.10 interval) was also determined for further evaluation and results showed that the Kozak model 02 had the lowest *AMD* in most of the relative height classes while the MB76 model still provided the poorest performance among the candidate models (Figure 3). According to Kozak and Kozak (2003), this evaluation method is important to be done because single overall value of the performance statistics may not provide the best stem taper model to predict DOB. For instance, Berhe and Arnoldsson (2008) explained that in bias, the negative and positive biases of a model in the different parts of the stem may have a cancelling effect which may provide a better overall bias (close to zero) even if the model fails to fit well in estimating the DOB in one or other portion of the tree. The performance of the four candidate modes in estimating the total volume of *Camellia japonica* was also evaluated. Using the Smalian formula, the volume in each log section was determined and these volumes were summed up to determine the total volume of each tree. The *AMD* was determined in different DBH classes (5 cm interval) and result showed that the Kozak model

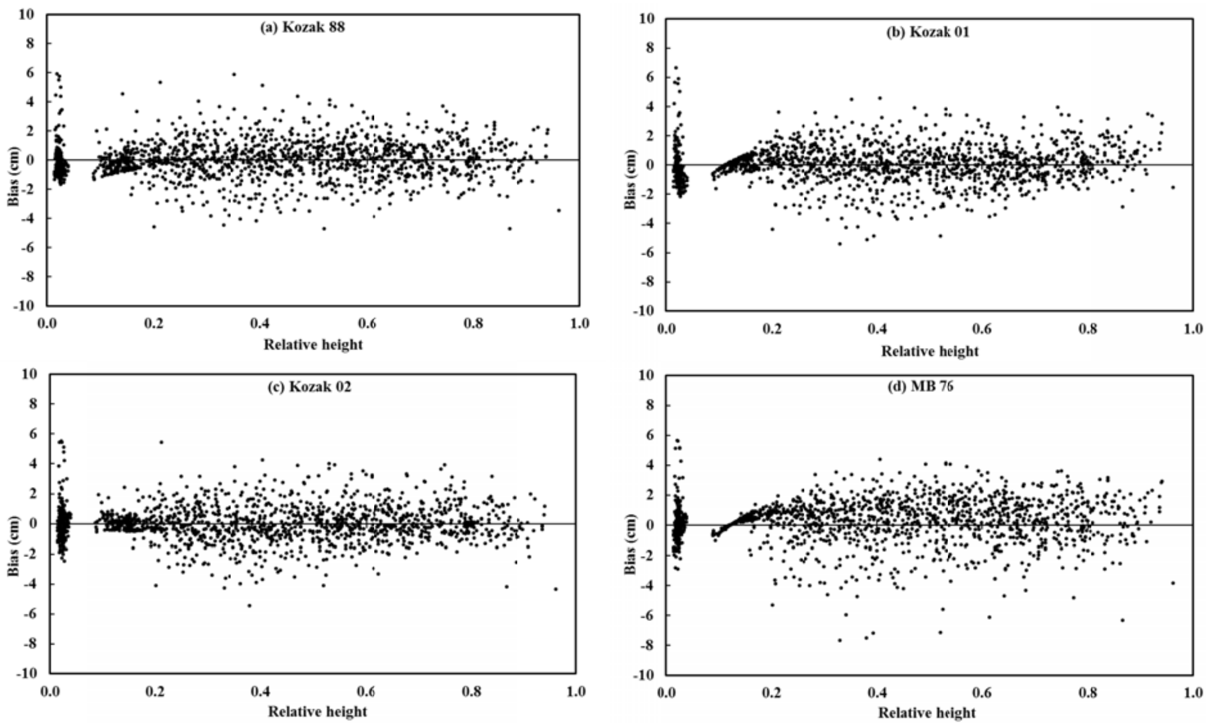

Figure 2 Biases of the four candidate models plotted against the relative height of *Camellia japonica* in Jeju Island, Korea.

02 had the best performance while the MB76 model still had the poorest performance as shown in Figure 4.

The superiority of the Kozak model 02 among the candidate models in this study is consistent with previous studies on stem taper modeling conducted for various species. Kozak (2004) conducted a comprehensive study that evaluated four models that he developed. Based on 38 species groups consisting of 53,603 trees, he concluded that Kozak model 02 was the overall best among the four models while the Kozak model 01 was the simplest in form. Rojo et al. (2005), on the other hand, evaluated the performance of 31 stem taper equations for *Pinus pinaster* in Galicia, Northwestern Spain. Based on the results of their study, MB76 stem taper model was selected as the best segmented model whereas Kozak model 88 and Kozak model 02 were selected as the two best variable-form models. Further evaluation and validation showed that Kozak model 02 was the best stem taper model for *Pinus pinaster* in Galicia, Northern Spain (Rojo et al. 2005). Furthermore, Berhe and Arnoldsson (2008) evaluated seven taper models for *Cupressus lusitanica* plantation in Ethiopia and they concluded that Kozak model 02 was the best model in predicting the DOB of this species. Li and Weiskittel (2010) concluded that among the 10 stem taper models that were fitted for *Picea rubens* and *Pinus strobus*, Kozak model 02 was the most accurate in predicting DOB. Heidarsson and Pukkala (2011) also selected the Kozak model 02 as a better stem taper model for *Pinus contorta* and *Larix sibirica* in Iceland, as compared to the taper equation developed by Biging (1984).

Since there was still no stem taper model available for *Camellia japonica* in Korea prior to this study, the two existing stem taper models developed for *Quercus acuta* (Chung et al. 2010) and *Quercus glauca* (Lumbres et al. 2014) in Jeju Island was compared to the best stem taper model of the present study (Kozak model 02). The $\overline{E}$ in the different relative height classes were determined and results showed that the model developed in the present study is much better than the previously developed stem taper models in predicting the DOBs of *Camellia japonica* (Figure 5). In most of the relative height classes, the previously developed stem taper models significantly under predicted the DOBs of *Camellia japonica* as compared to the Kozak model 02 of this study. This shows that stem taper equations should be species-specific to provide a more accurate estimate of stem DOBs and subsequently, volume (Sharma and Zhang 2004; Subedi et al.

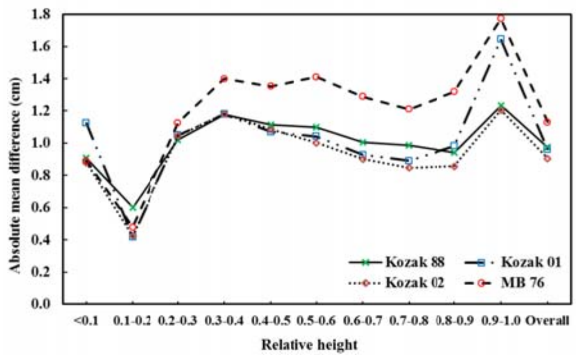

Figure 3 Absolute mean difference of the four candidate models in the different relative height classes of *Camellia japonica* in Jeju Island, Korea.

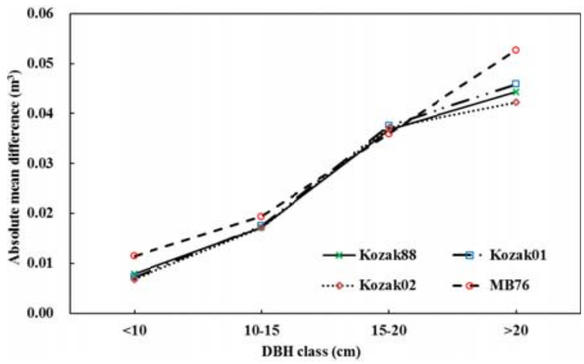

Figure 4 Absolute mean difference in the different DBH classes of the four candidate models in predicting the total volume of *Camellia japonica* in Jeju Island, Korea.

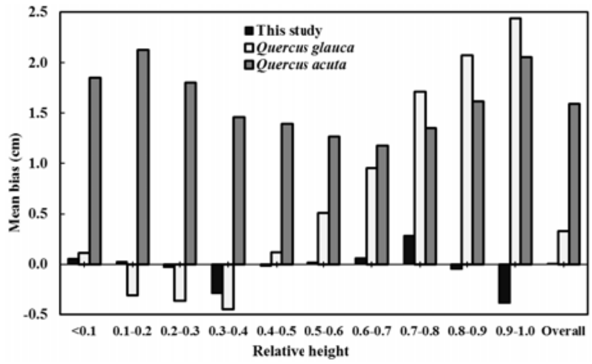

Figure 5 Comparison between the best stem taper equation of the present study (Kozak model 02) and stem taper model developed for *Quercus acuta* and *Quercus glauca* in estimating the diameter outside bark of *Camellia japonica* in Jeju Island, Korea.

2011; Li et al. 2012).

3 Application

Among the four candidate models, only the MB76 can be integrated between any two stem heights that resulted in a volume equation model (Martin 1981). This method was not used in this study and the recommendation of Li et al. (2012) was followed. They suggested two steps to predict the volume of a tree using stem taper model. The DOB in the different height position must be predicted using the best model (Kozak model 02) by substituting the estimated parameters in Equation 3. Then, the volume of the different log section can be determined using the Smalian's formula. For instance, a forest manager wants to determine the merchantable volume of a *Camellia japonica* with a DBH of 14 cm, total height of 10 m and merchantable height of 8.20 m. The DOBs starting from the stump height (0.20 from the ground) to the merchantable height, with intervals of 0.50 m, can be determined as follows:

$Z_1 = 0.20/10 = 0.02$,

$X_1 = [1\text{-}0.02^{1/3}]/[1\text{-}(1.3/10)^{1/3}] = 1.48$,

$Q_1 = (1\text{-}0.02^{1/3}) = 0.73$

$$d_1 = 1.2055 \times 14^{0.8821} \times 10^{0.0506} \times 1.48^{\{[-0.2230\times 0.02^4]+[-0.1878(1/e^{14/10})]+[1.0858\times 1.48^{0.1}]+[-2.6459\times(1/14)]+[-0.0128\times 10^{0.73}]+[-0.3294\times 1.48]\}}$$

$d_1 = 15.85$ cm

The DOB for the next height position ($h_2 = 0.70$ m) can also be determined as follows:

$Z_2 = 0.70/10 = 0.07$,

$X_2 = [1\text{-}0.07^{1/3}]/[1\text{-}(1.3/10)^{1/3}] = 1.19$,

$Q_2 = (1\text{-}0.07^{1/3}) = 0.59$

$$d_2 = 1.2055 \times 14^{0.8821} \times 10^{0.0506} \times 1.19^{\{[-0.2230\times 0.07^4]+[-0.1878(1/e^{14/10})]+[1.0858\times 1.19^{0.1}]+[-2.6459\times(1/14)]+[-0.0128\times 10^{0.59}]+[-0.3294\times 1.19]\}}$$

$d_2 = 14.97$ cm

This process can be done to every 0.5 m height position until the 8.2 m merchantable height. The volume for each section can now be determined using the Smalian's formula as shown below:

$V_1 = 0.00007854 \times [(d_1^2 + d_2^2)/2] \times L$

$V_1 = 0.00007854 \times [(15.85^2 + 14.97^2)/2] \times 0.5$

$V_1 = 0.0093$ m^3

By summing up the volumes from the different sections, the merchantable volume of this tree is 0.0659 m^3. This procedure can also be used to determine the stem volume of the tree or any section log volume. Li et al. (2012) recommended spreadsheet or other computer program to be used in the calculation as it is relatively easier than a pocket calculator.

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