早生樹種同齢林分の成長モデルに関する比較研究(生物生産学科)

Comparative studies of growth models of selected even-aged fast growing tree species*

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Key words: growth models, growth prediction, goodness of fit, mitscherlich function
キーワード：グロスモデル，成長予測，ミッチャーリッヒ式，熱帯性早生樹種

Summary

Generally, stand growth is affected by stand age, site quality, stand density, timber management regime and other factors. Based on this reasoning, the study deals with the development of a system of equations for the growth prediction of important tree species. Given the data on the average stand dbh, height, and vol/ha an analysis of growth curves was made for the 7 fast growing tree species using the Mitscherlich, Gompertz, Logistic, and the Modified Exponential functions. The parameters of these corresponding equations were determined by the least squares method and respective growth equations were derived and developed. Subsequently, by substituting the observed values to the corresponding parameters, the theoretical growth values were calculated and compared. Within the normative range of units and measures of stand age and growth parameters, the growth models resulting from this study can be rated as relatively efficient. A critical review of these models revealed that, in general, the Mitscherlich was the most appropriate equation to describe the growth of the tree species. Although the other three functions had satisfactorily fulfilled the representation of the growth course, they were not as good as the Mitscherlich. Similarly, a comparison on the growth of the tree species was conducted based on the developed models. The species of the Philippines are relatively considered fast growing in contrast to the species of Japan. The results demonstrated that the developed models are worthwhile to be utilized as a basis for an integrated stand growth prediction system.

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* Paper presented at the 7th Pacific Science Inter-Congress held in Okinawa, Japan on June 27－July 3, 1993

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Sci. Bull. Coll. Agr. Univ. Ryukyus 42：67～79 (1995)

Introduction

The forest regulatory system is composed of the following: Timber inventory and forest surveys; growth and yield prediction; rotation/cutting cycle determination; allowable cut determination; demand projection; cut allocation and scheduling; and forest development scheduling. The most basic component of the regulatory system is growth and yield prediction. Such prediction is a prerequisite to the other components of the system. Growth prediction is indispensable for effective timber production planning and a necessary basic item for optimal decision-making in timber management. Thus, predicting future growth of managed stands is absolutely essential to credible forest management planning. Hence, this study aims to contribute to the growing realization of the significance of growth models for rational forest management.

The specific objectives of the study are:

1) To develop reliable growth prediction functions applicable to even-aged fast growing tree species.
2) To compare the relative efficiency of the growth functions to selected even-aged fast growing species.
3) To identify possible problems that may be encountered in such studies.

Materials and methods

A.) Place and date of the study

The study made use of volume per hectare (vol/ha), diameter at breast height (dbh), and height (hgt) by age classes of species grown in the Philippines (Talacogon, Agusan del Sur), i.e., *Endospermum peltatum Merr.*, *Gmelina arborea Roxb.*, and *Acacia mangium Willd.*, and species widely grown in the Ryukyu and Kyushu islands of Japan, i.e., *Pinus luchuensis Mayr.*, *Casuarina equisetifolia J. et G.*, *Alnus formosana Mak.*, and *Castanopsis cuspidata*. There are two sources of data used in the study: 1) data obtained from Provident Tree Farms, Inc. (PTFI) plantation area, and 2) data used in the study by Dr. E. Hirata[4], Dr. I. Asato[1], and Dr. K. Tsujimoto[16]. The data from the Philippines were collected in 1990 in the forest concession area of PTFI covering 11,500 hectares in the municipalities of Talacogon and La paz, Province of Agusan del Sur, with a total of 94 plots for the 3 species. The forest concession is with in the climatic zone, the seasons of which maybe described as not very pronounced dry or wet. It is somewhat dry during the months of March, April and May and somewhat wet during the rest of the year, except during November up to January when rain is relatively pronounced. The elevation varies from 20 meters above sea level in the eastern section, up to 165 meters above sea level in the southwestern section, or a mean elevation of 100 meters above sea level.

The soil is generally light-gray in color, not very deep and covered with thick forest litter in most parts of the forest concession, except in the eastern flatlands where soil is of alluvial type. Rock outcrops are found in some places.

B.) Model development

The models used in this study are the following; 1) Gompertz function, 2) Logistics Function, 3) the Modified Exponential Curve, and 4) the law of effects of growth factors by A. E. Mitscherlich, otherwise known as the Mitscherlich function. The calculation procedures for the gompertz, logistic, modified exponential functions follow the steps provided for in appendix D of the book by Mills[6]. While that of the Mitscherlich function was based on that described by Prodan[8], and on a computer program developed by Tanaka[15].

The Gompertz Function

The Gompertz curve, which has important uses in actuarial science, was first introduced by Wright in 1926 and has been applied in the study of economic, business and biological trends[6]. For the purpose of fitting, the equation of the natural form is: $Y = ab^{c^t}$ and transformed into the logarithmic of the form: $log\ y = log\ a + (log\ b)\ c^t$ where $log\ a$ is the logarithm of the maximum value or the ceiling that the curve approaches, $(log\ b)\ c^t$ measures the amount by which the trend value at a given time falls short of the maximum, an amount that diminishes over time.

The Logistic Function

The logistic function represents a modiffied geometric progression, the growth of a series that tends to decrease as it approaches some specified limit. It is sometimes called the Pearl-Reed growth curve because of the intensive use made of it in population studies by Raymond Pearl and Lowell J. Reed in early 1920[6]. The form of the curve adapted for use as a measure of trend is defined by the equation; $1/y = a + b\ c^t$ where $1/y$ is the dependent variable, a, b, c are constants while t is the time, set at the date of the first observation.

The Modified Exponential Curve

The modified exponential curve is a suitable measure of trend for a series that is increasing or decreasing at a constant rate, i.e, one that shows constancy of relative growth and maybe accurately defined by a simple modification of the exponential curve. Thus, Frederick C. Mills[6] introduced this method for economics and business analysis. The form of the equation is defined as; $y = ab^t - K$ where y represents the ordinates of trend of the original series, K is correction factor, t represents time and a, b are constants to be determined by fitting an exponential curve.

The Mitscherlich Function

There is a "law" -the so called law of effects of growth factors, which has been defined by Alfred E. Mitscherlich (1874−1956) for practical application, is applied in economics and agriculture, and has a special growth function which states that the yield approaches a limit and that, therefore, the increase in yield tends towards zero[6,8]. It is of the form; $y = a\ (1 - e^{-kt})$ where t is quantity of growth factor, a is the maximum yield, k is the intrinsic rate of growth which represents a constant, and e is the base of the natural logarithm.

In developing the growth models, a preliminary analysis of the data from sample plots is needed. Age was determined from the date of planting. Dbh was measured, in cm., 1.3 meters from the ground while the measurement for total height was taken from all trees in the plot, whether dominant, codominant, and suppresed trees. The mean dbh and mean total height of all trees in each plot were calculated. Finally, the volume per tree was determined. Merchantable volume was calculated based from dbh and height up to 10 cm top for tree species of the Philippines, while total volume was used and calculated for the tree species of Okinawa. The corresponding volume of each tree tallied was multiplied by the number of trees per hectare, giving the volume it represented on a per hectare basis. The sum of the volumes represented by all accounted trees in a sample plot gives the stand volume in cubic meters per hectare.

Results and Discussion

A.) Growth Model Comparisons

Generally, stand growth is affected by stand age, site quality, stand density, timber management regime, and other factors. This study determined the effect of predicted dbh, total height, and vol/ha which is a function of

Table 1. Growth equations of the different tree species according to dbh, height, and vol/ha

	dbh	height	vol/ha
G. arborea			
Mitscherlich	$y=18.537(1-e^{-0.6145t})$	$y=18.52(1-e^{-0.27t})$	$y=389.647(1-e^{-0.02t})$
Gompertz	$\log y=1.286-0.068(0.83^t)$	$\log y=3.43-2.32(0.986^t)$	$\log y=1.67-0.24(0.65^t)$
Logistic	$10/y=0.513+0.094(0.84^t)$	$10/y=0.48+0.31(0.75^t)$	$10/y=0.194+0.171(0.748^t)$
Modiffied Exp.	$y=2.81(1.12^t)+12.813$	*	$y=0.63(1.837^t)+24.393$
A. mangium			
Mitscherlich	$y=25.76(1-e^{-0.2989t})$	$y=52.566(1-e^{-0.0798t})$	$y=288.17(1-e^{-0.0586t})$
Gompertz	$\log y=1.89-0.69(0.956^t)$	$\log y=1.33-0.35(0.404^t)$	$\log y=2.01-0.42(0.712^t)$
Logistic	$10/y=-0.0579+0.693(0.94^t)$	$10/y=0.468+0.262(0.501^t)$	$10/y=0.093+0.065(0.86^t)$
Modified Exp.	$y=8.86(1.067^t)+7.167$	$y=1.857(1.25^t)+10.06765$	*
E. peltatum			
Mitscherlich	$y=41.845(1-e^{-0.0659t})$	$y=24.97(1-e^{-0.14t})$	$y=176.587(1-e^{-0.047t})$
Gompertz	$\log y=1.47-0.22(0.89^t)$	$\log y=1.51-0.305(0.935^t)$	$\log y=2.06-0.434(0.923^t)$
Logistic	$10/y=0.34+0.216(0.897^t)$	$10/y=0.184+0.429(0.95^t)$	$10/y=-0.1755+0.407(0.983^t)$
Modified Exp.	$y=5.86(1.089^t)+11.296$	*	*
C. equisetifolia			
Mitscherlich	$y=32.515(1-e^{-0.0325t})$	$y=18.88(1-e^{-0.0796t})$	$y=590.354(1-e^{-0.024t})$
Gompertz	$\log y=1.899-1.134(0.98^t)$	$\log y=1.98-1.19(0.97^t)$	$\log y=2.95-1.33(0.9298^t)$
Logistic	$10/y=0.116+2.196(0.93^t)$	$10/y=0.354+1.33(0.902^t)$	$100/y=0.25+1.93(0.81^t)$
Modified Exp.	$y=1.856(1.145^t)+2.828$	$y=8.788(1.05^t)-3.029$	$y=80.20(1.09^t)-39.5265$
A. formosana			
Mitscherlich	$y=44.899(1-e^{-0.0255t})$	$y=21.29(1-e^{-0.074t})$	$y=522.556(1-e^{-0.047t})$
Gompertz	$\log y=1.61-0.75(0.97^t)$	$\log y=2.34-1.45(0.98^t)$	$\log y=2.70-0.76(0.89^t)$
Logistic	$10/y=-0.182+1.737(0.93^t)$	$10/y=0.21+1.063(0.925^t)$	$100/y=0.24+0.843(0.8^t)$
Modified Exp.	$y=3.28(1.076^t)+2.646$	$y=11.54(1.028^t)-4.44$	$y=499.17(1.02^t)-394.167$
C. cuspidata			
Mitscherlich	$y=35.15(1-e^{-0.014t})$	$y=14.92(1-e^{-0.053t})$	$y=677.97(1-e^{-0.018t})$
Gompertz	$\log y=2.206-1.52(0.986^t)$	$\log y=6.23-5.41(0.998^t)$	$\log y=2.96-1.022(0.966^t)$
Logistic	$10/y=0.686+3.46(0.889^t)$	$100/y=1.35+28.97(0.945^t)$	$100/y=0.45+2.137(0.804^t)$
Modified Exp.	$y=4.38(1.04^t)+0.74$	$y=7.79(1.024^t)-1.4437$	$y=227.068(1.0298^t)-139.128$
P. luchuensis			
Mitscherlich	$y=76.61(1-e^{-0.0098t})$	$y=17.296(1-e^{-0.043t})$	$y=617.84(1-e^{-0.014t})$
Gompertz	$\log y=2.68-1.85(0.989^t)$	$\log y=1.62-0.83(0.979^t)$	$\log y=4.04-2.13(0.992^t)$
Logistic	$10/y=0.18+1.74(0.928^t)$	$10/y=0.486+0.13(0.937^t)$	$100/y=0.156+1.6(0.932^t)$
Modified Exp.	$y=4.72(1.05^t)+1.686$	$y=33.23(1.01^t)-27.498$	*

* not possible because when fitted will yield negative values that can not be transformed into natural logarithmic form

stand age on the growth of selected fast growing tree species. Various growth models were tried in this study.

The general form of these models were formulated so that;

1) Based on the analysis of the factors affecting growth, with the management regime and other factors held constant, growth is expressed as a function of stand age;
2) Each model is composed of a set of equations; and
3) Respective equations for each of the tree species were developed, tabulated and presented

The parameters of the corresponding equations in each of the tree species were determined by least squares method and respective equations were derived and given in Table 1. Subsequently, by substituting the observed growth values for the corresponding parameters, the theoretical growth values were calculated for each growth equation and compared to the corresponding observed values.

The theory upon which the method of least squares is based will not be detailed at lenght here. The argument, however, maybe briefly presented: *a number of observation values of a certain quantity are found, and it is desired to obtain the most probable value of the quantity which is being measured. It is capable of demonstration that the most probable value of the quantity is that value for which the sum of squares of the residuals is a minimum.* Fitting these values is widely known as the goodness-of-fit.

Although the goodness-of-fit alone cannot be absolute basis, there is no doubt that it is one of the important criteria for choosing the best equation for the growth of trees. It is capable of demonstration that the most probable value of the quantity is that value for which the sum of squares of the deviation (SSD) between the observed and the predicted is a minimum. Thus, by comparing the SSD values we can tell which of the growth equations gives the best prediction in comparison to the others. By definition, the smaller the SSD value, the closer is the fit.

Sweda and Koide[11] evaluated the goodness-of-fit of white spruce growth equations by the SSD of the calculated values from the corresponding observed values that is:

$$SSD_i = \Sigma\,(Y_i - y_i)^2$$

where SSD_i = sum of squared deviation for the ith observation

Y_i = observed vlues

y_i = calculated values

Since all the growth equations they employed have the same number of parameters, i.e. the same degree of mathematical freedom, this measure of the quality of fit provides a fair basis of the comparison among the equations. However, Sweda and Kouketsu[12] demonstrated a fair comparison among growth equations with different numbers of parameters by this equation:

$$SSD_i = \Sigma\,(Y_i - y_i)^2 / n - f$$

where SSD_i = sum of squared deviation for the ith observation

Y_i = observed values

y_i = calculated values

n = total number of observations

f = no. of parameters involved in the equation concerned

According to Nagashima *et al*[7], it is a mathematical rule of thumb that apparent goodness-of-fit improves as the number of parameters involved in an equation increases, and the calculated curves exactly coincide with the observations when the number of parameters matches the number of observations. The subtraction term *f* in the denominator of the latter equation counter balances this bias and provides a fair basis for a comparison of the mathematical expressions with different number of parameters. Since this study compared equations with different number of parameters the latter equation was, therefore, employed. The subtraction term f for the Mitscherlich is two, i.e. a and k, and three for the other equations. The values of the SSD of the different growth equations of each respective tree species are calculated and presented in table 2.

Table 2. Calculated SSD values of the different growth equations by species

Specie	Mitscherlich			Gompertz			Logistic			Modified exponential		
	dbh	hgt	vol/ha	dbh	hgt	vol/ha	dbh	hgt	vol/ha	dbh	hgt	vol/ha
A. mangium	1.13	6.40	418.25	8.86	12.18	105.93	9.35	14.86	139.54	6.93	19.97	*
G. arborea	0.18	21.67	16.93	0.94	14.84	174.05	0.94	12.90	195.07	1.16	*	290.28
E. peltatum	14.17	13.22	155.94	24.09	14.45	337.82	37.38	14.53	311.89	10.13	*	*
C. equisetifolia	0.12	0.41	276.66	4.55	60.15	320.76	148.74	17.47	99.00	77.73	16.59	330.17
A. formosana	0.67	0.47	10.72	11.08	10.11	17.79	38.82	7.30	10.69	12.97	5.66	31.20
C. cuspidata	6.70	3.09	33.94	12.78	9.04	76.15	10.74	25.96	105.67	8.83	8.96	185.10
P. luchuensis	16.33	3.13	36.44	84.19	15.27	104.77	49.95	5.98	91.89	117.95	51.79	*

*not possible in fitting

All throughout the analysis in this study it was observed that the occurence of smaller values of SSD are predominant in the Mitscherlich equations. Exceptions are some growth equations which gives smaller values of SSD, i.e. Logistic equation for *G. arborea* total height, and *A. formosana* volume equation, although it differs only slightly with Mitscherlich, and the modified exponential function for *E. peltatum* (Gubas) dbh equation.

As cited by Sweda[10] the applicability of these equations (excluding the modified exponential function) to the growth of trees has been studied extensively. Sweda and Koide[11] and Sweda and Kouketsu[12] indicated the general superiority of the Mitscherlich in such criteria as the goodness-of-fit.

A preliminary fitting of the calculated values of the developed equations was conducted to further compare the consistency of the developed models. During the course of the analysis, the Logistic equation gave a sufficient fit only twice out of the 21 growth equations while the modified exponential was better only once. The Gompertz is a poorer fit in all species. This might be particularly true because in fitting, random fluctuational errors of great magnitudes were observed in both dbh, height and vol/ha especially in tree species of the Philippines. This gives inconsistency in the growth parameters, with exception of the Mitscherlich equation which, as given by its low SSD values, demonstrated a superior degree of fit. Although the other growth equations gave acceptable growth trends, they were not as good as the Mitscherlich.

This can be verified from logical theory which has been defined and discussed by Prodan[8]. According to the theory, a growth curve generally takes the shape of a sigmoid, begins at the value zero, climbs slowly at first and then more steeply. After a turning point, the gradient of the curve (i.e the increment) diminishes and then asymptotically moves toward some final value. Furthermore, when Sweda and koide[11] classified the Mitscherlich, Logistic and Gompertz as general theoretical equations, they postulated that the parameter a of these equations are, undoubtedly, supposed to be the asymptotic values of the measured elements that the tree species will ultimately attain in the future. As seen in table 1, the calculated asymptotic values of the diameters, heights, and vol/ha by the Mitscherlich equation are the only values that were consistent with the theory. Thus, the Mitscherlich results are the only curves considered in the comparison and are presented in figures 1 through 4.

It can be seen that the curves, as a function of stand age, begin at zero, climbs up and likewise tend to attain the asymtotic value of the parameter a as they approached the final stages of growth. The curves have considerable flexibility and represent growth fairly well in their own respective ways, which are weaving its way

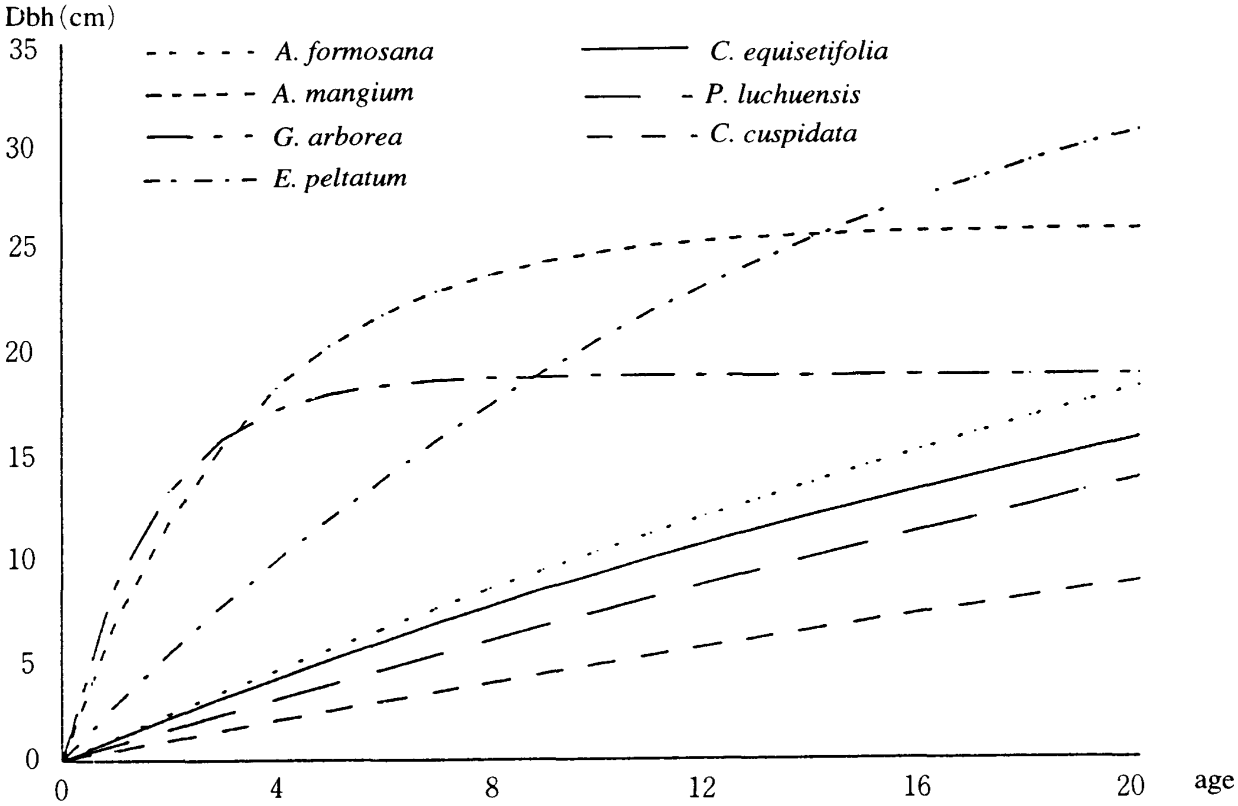

Fig.1. Dbh growth curve comparison of the seven tree species as predicted by the Mitscherlich function

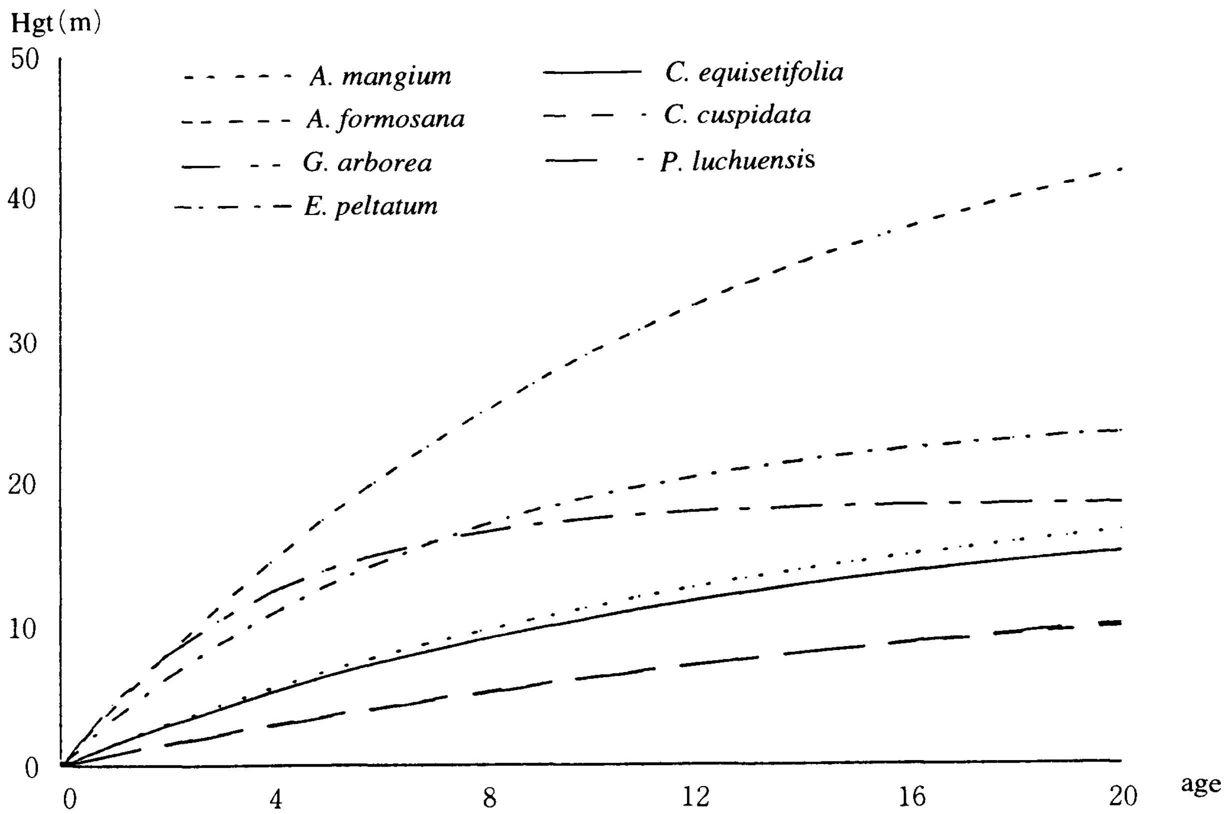

Fig.2. Height growth curve comparison of the seven tree species as predicted by the Mitscherlich function

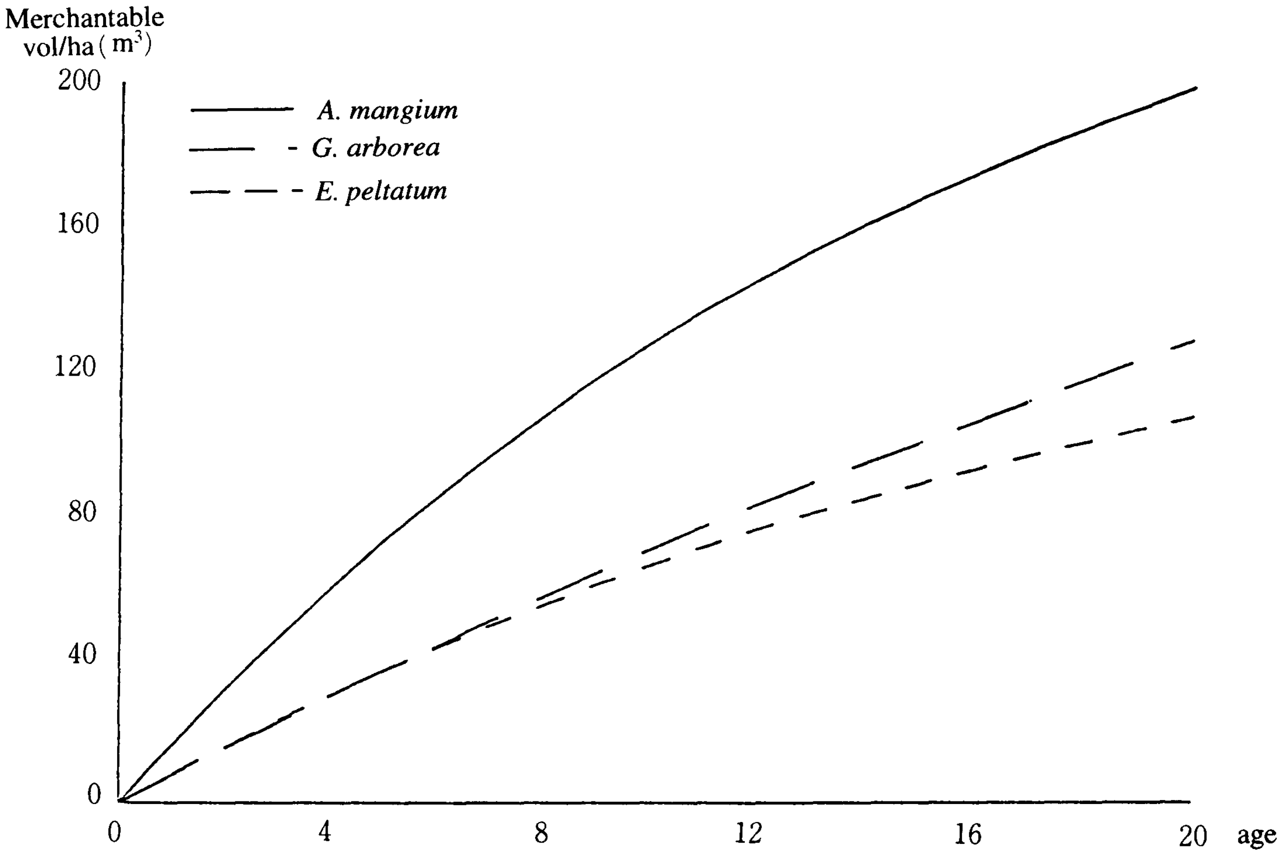

Fig.3. Merchantable vol/ha growth comparison of tree species of the Philippines as predicted by the Mitscherlich function

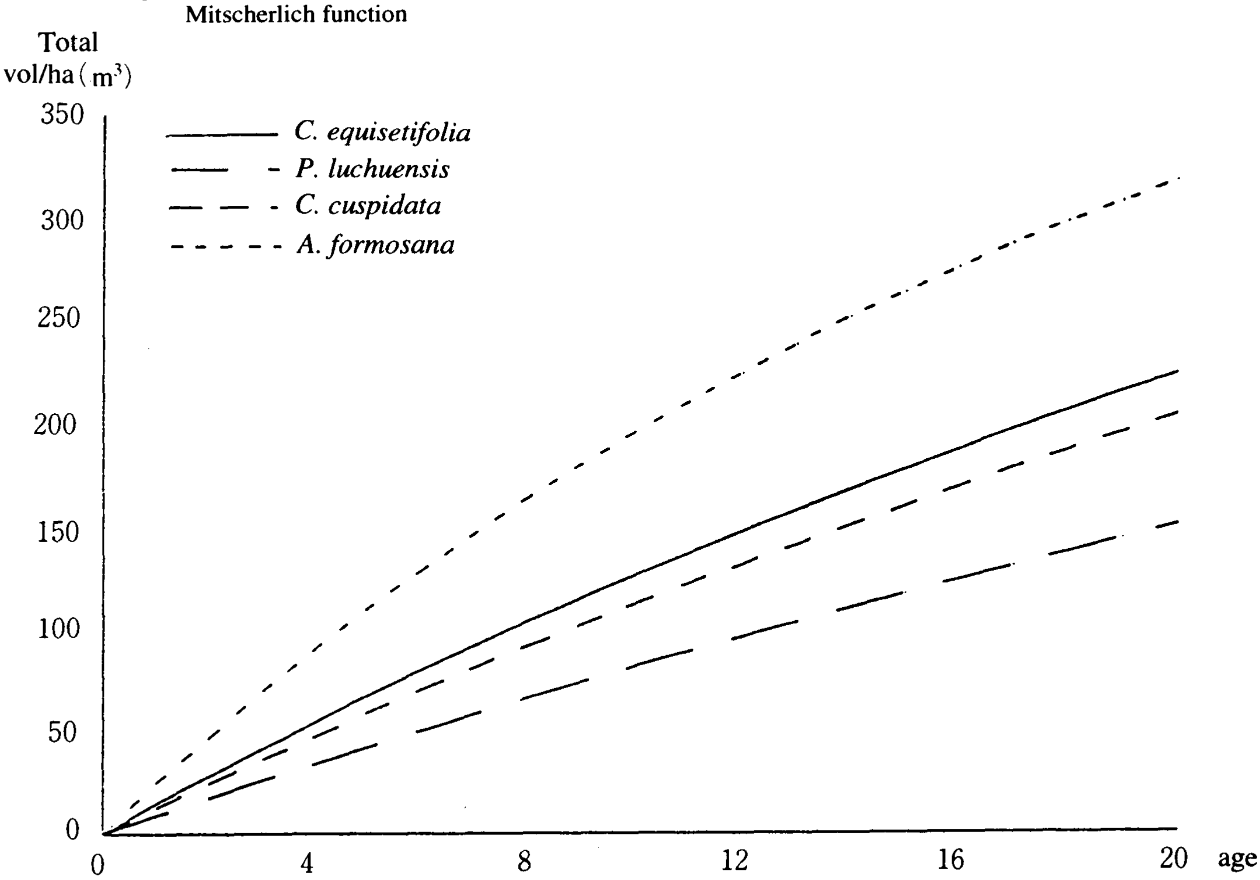

Fig.4. Total vol/ha growth comparison of tree species in Japan as predicted by the Mitscherlich function

representing the hypothetical mean course of growth. This fact indicates that the growth curves as well as its coresponding asymptotes conform to the theory. Thus, as far as the curves and the asymptotes of the estimated parameters are concerned the results of fitting are quite satisfactory. This reasoning was also used by Nagashima *et al*[7] and Sweda *et al*[13] who observed that the Mitscherlich curve generally exhibits a remarkable degree of fit and is a suitable equation in expressing the diameter and height growth of forest trees. Accordingly, Takeuchi[14] also demonstrated the usefulness of the Mitscherlich in predicting stand volume. Hence, in general, the Mitscherlich provides a good fit and is a suitable equation for use in growth prediction for all the species in this study.

On the part of the modified exponential function, it should be noted that, not with standing its extensive usage in practice and research, it is just an empirical or experimental one. It is simply a mathematical expression with a graphical resemblance to the observed course of growth but without any assumptions or physical meaning. As referred by Sweda and Koide[11], these function is useful for interpolation but little else.

Also, figures 1 through 4 compare the growth of the seven tree species at 20 years as base age as predicted by the Mitscherlich equation. It can be observed that growth of the species from the Philippines ranges from about 18 cm to 30 cm in average dbh, and 18 m to 40 m in average total height, respectively. This is in contrast to the species grown in Japan which, can not be considered economically valuable at this range of age. As predicted by the models, the species from the Philippines are relatively considered fast growing. Considering the silvical characteristics of these species, they both show remarkable growth in their respective habitat. The importance in this aspect is of the model's efficiency and applicability in predicting growth of these species. As cited by Chong and Jones[2] *G. arborea* has economic potential-end usage at the ages between 8 to 12 years. The same is true to *A. mangium* as reported by Jones[5] and Ramos for Gubas[9]. The calculated growth value in this study by the prediction models reveals a similar observation on their growth. Thus, it can be said that the prediction models developed in this study are applicable to the growth analysis of these species.

B.) Model Validation

For a more statistically rigorous comparison in the goodness-of-fit, a paired bilateral t-test of significance was conducted. It was used to perform a pairwise comparison between the values of the actual growth and the values predicted by the best equation. This evaluated the difference between the observed and the predicted values to show that there is no significant difference between them.

The null and alternative hypothesis are:

$$Ho : UD = 0$$

$$Ha : UD = 0$$

where; UD = population mean variance

The differences are calculated by:

$$d_i = P_i - O_i$$

where; P_i = observed value

O_i = predicted value

One method of making an inference about the mean diference (UD) is by a test of significance. For sample data, the distribution of t furnishes the test. It is given by the equation

$$t = \frac{\overline{d_i}}{S_{d_i}\sqrt{n}}$$

where;

$$d_i = \frac{1}{n} \sum_{i=1}^{n} \overline{d_i}$$

$$Sd_i = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (d_i - \overline{d_i})^2}$$

n = no of observations

If the calculated t-value is greater than the tabular t-value, it points to rejection of Ho, i.e. there is a significant difference exists between the observed and the predicted values. The results of the paired t-test are tabulated in table 3.

Table 3. The t-test of the significance on the goodness of fit of the models

Specie	Dbh/ t-calc.	Height/ t-calc.	Volume/ t-calc.	t-tabular	
				0.05	0.01
A. mangium	.4927	.2992	.4931	2.776	4.604
	n.s	n.s	n.s		
G. arborea	.4948	.2577	.4781	3.182	5.841
	n.s	n.s	n.s		
E. peltatum	.1406	.4897	.4321	2.262	3.250
	n.s	n.s	n.s		
C. equisetifolia	.4585	.4756	.3236	2.131	2.947
	n.s	n.s	n.s		
A. formosana	.4668	.3994	.3161	2.145	2.977
	n.s	n.s	n.s		
C. cuspidata	.4512	.4409	.4532	2.060	2.787
	n.s	n.s	n.s		
P. luchuensis	.428	.4694	.4947	2.042	2.750
	n.s	n.s	n.s		

n.s=not significant

As we can see in table 3, the reults of the paired t-test of significance on the goodness-of-fit of the models showed that the calculated t-values for the best models are less than the tabular t-values at 0.05 and 0.01 levels of probability, respectively. This implies that there exists no significant difference between the observed values and the values as predicted by each respective model. The lack of significance in all tests was taken as evidence of acceptability of the prediction models which generated the test values at the stipulated levels of significance.

Conclusion and Recommendation

This study deals with the development of a system of equations for the growth prediction of the seven important tree species. The emphasis was placed on the development of a set of average dbh, average total height and vol/ha equations as well as the theoretical assumptions underlying the estimation of growth parameters.

With in the normative range of units and measures of stand age and growth parameters, the growth models resulting from this study can be rated as relatively efficient. A classification and critical review of numerous growth equations revealed that in general, the Mitscherlich would be the most appropriate equation to describe the growth of the seven tree species. Although the other three functions satisfactorily fulfilled the presentation of the growth course, they were not as good as the Mitscherlich. Moreover, since the equations used are based on the assumption which postulates the mechanism of growth in general terms as a function of stand age, there is no positive reason why it should not be applicable. Thus, it makes the Mitscherlich equation suitable to a wide variety of growth phenomena rather than to a specific one. This system of growth models adequately and consistently described the development courses of the diameter, total height, and vol/ha. Therefore, the developed models are worthwhile to be utilized as a basis for an integrated stand growth prediction system.

From the results, some basic information can be derived, such as the determination of the species' economic rotation for valuable purposes, and the evaluation of site productivity in its locality. These will be useful in some studies aiming for the optimization of timber production flow.

To a certain degree, although the system of growth models yielded results that are not necessarily inferior to those that are obtained from plot data, a minimal amount of the variation in growth values and parameters has been left unexplained. Since in the practical approach to a problem involving the determination of growth trend, the first task is the selection of the appropriate type of curve. This is perhaps the most difficult part of the work. Certainly it is the part in which the element of personal judgement enters most directly, for there is no objective rule to follow, and no fixed standard by which the most appropriate curve may be selected. The primary significance of a growth equation exists in its operational convenience of putting unwieldly masses of numerical data into a concise and perspective view. In appreciation of this condensing function, numerous equations have been presented to date. Ironically, however, this proliferation of growth equations now makes it difficult and sometimes impossible for the users to decide upon which one to choose for a specific purpose and objective.

This dependency of the superiority/inferiority of an equation makes it difficult, with the present state of knowledge, to arrive at any decisive conclusion as to whether the developed equation is really best for predicting the growth of trees. To make this point clear, it is recommended that further research is needed on their practical characteristics and feasibility. This should include: 1) An investigation into the goodness-of-fit to numerous actual data, especially in comparison with the other existing growth curves, whether emperical or theoretical, and 2) The determination of the numerical ranges of parameters and their relationship with the different types of forest stands including the different stand variables such as site index, stand density, and others.

Although the developed model showed a high reliability of prediction accuracy, it has certain limitations. It should only be used for predicting growth in places where the data were collected. Its application must be with in the range of these data. The data were also based on age limitations, especially those data from the Philippines. With more data from older stands, the effects of other factors could have been satisfactorily determined. Thus, the models can only be safely used within the age range unless adequate provisions are made to allow for valid extrapolation or projection. Beyond these ranges, estimates are likely to become biased and inconsistent.

This study was conducted by D. Paler under the guidance of Dr. I. Asato and Prof. T. Shinohara. Sincere appreciation is hereby extended. The authors gratefully acknowledged the support and cooperation of Dr. M. Ueno of the College of Agriculture, Univ. of the Ryukyus and of Mr. R. Terazuno of the Okinawa For. Expt. Station for the development of computer programs used in the study. Similarly, the authors thank the Provident Tree Farms, Inc. for providing the data from Philippines.

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早生樹種同齢林分の成長モデルに関する比較研究

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要　約

本研究は，早生造林樹種の成長予測に資する目的でいくつかの成長モデル式の適応性について検討を試みたものである。7樹種（フィリピン3，沖縄3，九州1）について，林分平均胸高直径，平均樹高，ha当り立木幹材積を資料にミッチャーリッヒ，ゴンペルツ，ロジステック，修正指数の各式について分析した。各々の式は係数を最小自乗法で算定して得た。各式の当該パラメタに観測値を代入してその理論値を算出し，式の適応性を比較検討した。林齢や成長に関係するパラメタ等供試資料の範囲内においては，得られたモデル式は相対的に有効と評価できるが，総体的にミッチャーリッヒ式が最適であると言える。他の3式は成長過程を示すことはできても，ミッチャーリッヒ式ほど良好とは言いがたい。同様に算定されたモデルに基づいて，各々の樹種についても比較を行った。フィリピンの供試樹種は沖縄，九州の樹種に比べて成長が早い。これらの結果は，得られたモデル式が林分成長予測システムを調製するための基礎として利用することに有効であることを示している。

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