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Full Length Research Paper

The leaf growth model and influencing factors in *Phalaenopsis* orchid

Chiachung Chen[1]* and Meiyu Chien

[1]Department of Bio-industrial Mechatronics Engineering, National ChungHsing University, 250 Kuokuang Road, Taichung Taiwan.
[2]International Master Program of Agriculture, National ChungHsing University, 250 Kuokuang Road, Taichung Taiwan.

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To evaluate the factors affecting the growth characteristics of *Phalaenopsis* leaves, the leaf-length growth patterns of two *Phalaenopsis* varieties, the red-flower *Phalaenopsis* clones 'LB9506' and 'LB9508', were measured under different environment condition such as day temperature, light intensity, and fertilizer rates. The fitting-agreement of three nonlinear growth equations was compared for evaluating leaf-length data for two varieties. The parameters of the adequate equation then were further studied. The results indicated the logistic equation was the best equation for describing the relationship between leaf-length and culture days. The parameters of this equation could be interpreted biologically. Environmental conditions and fertilizer rates had a significant effect on the maximal leaf-length for two varieties. The growth rate of one variety, 'LB9506', was influenced significantly by day temperature and light intensity. However, the growth rate of the other variety, 'LB9508', was not affected. As the plant growth data were fitted with the nonlinear growth equations and the parameters analyzed, it was discovered that this method was useful in studying the factors affecting *Phalaenopsis* leaf growth characteristics.

Key words: Growth equation, nonlinear regression, *Phalaenopsis.*

INTRODUCTION

Phalaenopsis orchids have become the highest value potted plants in the world. To ensure the quantity and quality of the orchid production, the effects of plant growth factors, such as temperature, light intensity and fertilizer concentrations need to be understood.

Healthy leaves are the basic requirement for *Phalaenopsis* cultivation. Photosynthesis and transpiration are involved in leaf development. The growth of leaves involves energy transfer, mass accumulation and transportation. The development of the leaf-length is influenced by temperature, light intensity, fertilization management and other factors (Dwyer and Stewart, 1986). The optimal conditions of these factors are important for the orchid growers. Lopez and Runkle (2004) measured the leaf and flower development of *Zygopetalum* Redrale 'Fire Kiss' Orchid under five temperature conditions. The authors found that the required period to unfold one leaf was decreased as temperature increased.

The plant growth model is useful in describing the relationship between the plant growth index and growth time (Thornley and Johnson, 1990). The parameters of these models need to be interpreted biologically. The influence of affecting factors then could be evaluated by the parameter value. Khamis et al. (2005) proposed several leaf-length models to demonstrate the usefulness of the research for crop managements. Karadavut et al. (2010a) compared the fitting-agreement of several nonlinear leaf growth models for five maize cultivars. Joly and Hahn (1989) used the modified logistic equation to describe the leaf expansion of cacao seedlings and adopted the parameters of this equation to explore genotypic differences in response to water stress. This

*Corresponding author. E-mail: ccchen@dragon.nchu.edu.tw. Tel: 886-4-22857562. Fax: 886-4-22857135.

modified logistic model provided an accurate quantitative description of leaf growth patterns. de Visser and van den Berg (1998) developed a two-parameter logistic model to describe the relationship between onion bulb weight and culture days and used it to calculate the optimal plant density. Willcutts et al. (1998) selected three mathematical models, the quadratic, the linear-plateau and logistic equation to estimate the fertilizer N (nitrogen fertilizers) requirements of lettuce and found the logistic model was the best fit for evaluating the lettuce responses to applied N. Godoy et al. (2008) compared the fitting-agreement of five nonlinear models in analyzing the growth pattern of blueberry fruit diameter of different cultivars. Barker et al. (2010) measured the patterns of herbage accumulation by time and location and found that the Gompertz equation could be best in describing the growth pattern. Karadavut et al. (2010b) measured the relative growth rate of three silage corn cultivars and evaluated the fitting-agreement of nonlinear growth equations for analyzing these data. The Weibull equation showed better fit than the other growth equations for all of cultivars.

The objectives of this study were (1) to measure the leaf-length of two *Phalaenopsis* orchid varieties under different temperatures, light intensity and fertilizer concentrations, (2) to compare the fitting-ability growth equations for evaluating leaf-length data, (3) to evaluate the factors affecting the growth characteristics of leaves by the parameters of the best fit growth equation.

MATERIALS AND METHODS

Model development

The growth indexes of orchids include the leaf-length, leaf area, fresh weight or dry weight. The leaf-length is considered the most important index of dry matter accumulation (Lopez and Runkle, 2004). The growth leaf-length is a function of time (t).

$$L(t) = f(t) \quad (1)$$

The growth rate is expressed as:

$$\frac{dL}{dt} = f(L,t) \quad (2)$$

The simplest equation is to assume that growth rate is proportional to the length, the governing equation is:

$$dL/dt = \mu L_s \quad (3)$$

where μ is the growth rate and L_s is the substrate level of the model.

The growth of living organs had its limitation. If the assumption of the growth rate is proportional to a substrate level L_s, the final leaf-length is L_f

$$L_f = L_s + L(t) \quad (4)$$

Combining Equations (3) and (4) resulted in the following:

$$dL/dt = K_2\ (L_f - L(t)) \quad (5)$$

$$L(t) = L_f + c_1(1-\exp(-K_1 t)) \quad (6)$$

Equation (6) is the monomolecular equation.
If the growth rate is assumed to be proportional to the substrate L_s and length L, then:

$$dL/dt = K_2\ L(L_f - L) \quad (7)$$

$$L = \frac{L_f}{1+(\frac{L_f}{L_0}-1)\exp(-K_2 t)} \quad (8)$$

where L_0 is the initial length.

This equation is the logistic equation.
If the growth rate is assumed to be an exponential function of the time, then:

$$K_g = K_0 \exp(-Dt) \quad (9)$$

$$dL/dt = K_0 \cdot L \cdot \exp(-Dt) \quad (10)$$

$$L = L_0 \exp(K_3(1-\exp(-Dt))) \quad (11)$$

where K_0, D and K_3 are constant. Equation (11) is the Gompertz equation.

These equations are derived from the mechanical function of growth. The parameters of some empirical equations, such as the higher-order polynomial equation, cannot provide any biologically meaning. The parameters of the above-described equations, derived by theoretically can be interpreted biologically. The L_f value of the monomolecular and logistic equations expresses the maximal length; it is explained as the maturing index. The parameter, K_1, K_2 and K_3 represents the growth rate under specific conditions.

Plant materials

The red-flower clones *Phalaenopsis* ‘LB9506’ and ‘LB9508’, cultured by LeBio Orchids Co. (Tainan, Taiwan), were used in this study. Plants with a leaf span of 20 to 25 cm, and with three and a new leaves, were grown in 9 cm plastic pots filled with sphagnum moss. All plants were placed in benches in different compartment of the same greenhouse. The greenhouse environment was controlled with a computerized control system. The plants were fertilized with 20 N - 20P - 20K liquid fertilizer (Hyponex Corp., Marysville, OH) in different concentrations. The moisture content of the sphagnum moss medium was detected by a WET meter (Delta-T, Delta Co., UK). Plants were irrigated or fertilized when the moisture content was less than 15% (wet basic).

Experimental design

Four experiments were conducted simultaneously in the same greenhouse in Shanhua town, Tainan Taiwan. Experimental design included two day temperatures and two light intensities. The low temperature region was near the pad side of the greenhouse and the high temperature region was close to the side of exhaust fans.

The high light intensity was the actual light intensity of the experimental greenhouse. The low light intensity was created with the 50% shading nets. The experiment was conducted from November 2008 to February 2009. The temperature and relative humidity of four regions were recorded by using of the EJ - HS - B8 data logger (Escort Co., UK). The light intensity was recorded by using of the HOBO S-LIA PAR meter and data logger (HOBO H8, Onset computer Corp., Bourne, ME). All sensors were placed at canopy level.

The four experimental conditions were as follows:

1. High day temperature and high light intensity (HTHL): 26-30℃, 200-280 μmol $m^{-2} s^{-1}$
2. High day temperature and low light intensity (HTLL): 26-30℃, 150-210 μmol $m^{-2} s^{-1}$
3. Low day temperature and high light intensity (LTHI): 23-27℃, 200-280 μmol $m^{-2} s^{-1}$
4. Low day temperature and low light intensity (LTLI): 23-27℃, 150-210 μmol $m^{-2} s^{-1}$

Plants in each region were fertilized with three fertilization concentrations. The fertilizer rates were 167, 250 and 333 mgL^{-1} and its symbol was LF, MF and HF. Each treatment had ten plants.

Leaf- length measurement

The sample plant had three fully developed leaves and a new leaf. The length of the new leaf ranged from 0.7 to 1.8 cm. The leaf-lengths of all plants were measured at different days. The day interval was 5 days. The length of the new leaf for each plant was measured nondestructively with an electronic digital caliper.

Statistical analysis

Three leaf-length growth equations are used in this study:

1. The monomecular equation:

$$L_1 = L_{f1} + a_1(1-\exp(-b_1 t)) \quad (12)$$

where L_{f1} is the final leaf-length in cm, a_1 and b_1 are constants.

2. The logistic equation:

$$L_2 = \frac{L_{f2}}{1+\exp(-b_2(t-x_0))} \quad (13)$$

where L_{f2} is the final leaf-length in cm, b_2 and x_0 are constants.

3. The Gompertz equation:

$$L_3 = a_3 \exp(-\exp(\frac{t-c_3}{b_3})) \quad (14)$$

where a_3, b_3 and c_3 are constants.

The association of leaf-length and culture days was examined by nonlinear regression analysis. Data were analyzed using Sigma Plot v.10.0 (SPSS Inc., Chicago, IL. USA) to evaluate the fitting ability of these growth equations. Two quantitative criteria, coefficients of determination, R^2 and standard error of the estimated value, s were adopted. The criterion to evaluate the adequateness of these equations was the residual plots. If the distribution of data points revealed a horizontal band centred on zero, it indicates that the nonlinear equation could be an adequate model.

The parameters of the best-fit equation for leaf-length were then further analyzed by the ANOVA followed by Tukey's post-hoc LSD analysis. The two-way ANOVA was used to evaluate the effect of environmental conditions and fertilizer rate.

RESULTS AND DISCUSSION

Leaf-length growth curves

The leaf-length growth curves for *Phalaenopsis* 'LB9506' with three fertilizer rates under HTHL are shown in Figure 1. The growth of the leaf-length was nearly an S shape. The leaf-length treated with 333 and 250 mgL^{-1} fertilizer rates was similar. However, leaf-length was the smallest in the low fertilizer treatment.

Typical leaf-length growth curves for 'LB9506' treated with 333 mgL^{-1} fertilizer rate under different environmental conditions are presented in Figure 2. HTLL seemed to enhance the growth of the leave. The growth with other conditions was similar and difficult to compare it visually.

The leaf-length growth for 'LB9508' with three fertilizer rates under HTHL is shown in Figure 3. The leaf-length obtained with 167 mgL^{-1} fertilizer rates was lower than that with the 333 and 250 mgL^{-1}.

The leaf-length for 'LB9506' differed significantly from that of'LB9508' (Figure 4.) The best culture condition was HTHL and treated with 333 mgL^{-1} fertilizer rate. The result showed different growth characteristics of the *Phalaenopsis* varieties. Under the same culture conditions, the leaves growth curves of two varieties were significantly different.

The effect of environmental factors (temperature and light intensity) and management technique (fertilizer rate) on the growth of the leaf was not easy to observe visually. These data were further analyzed by the comparison of the nonlinear equation.

Models for leaf- length growth characteristics

The leaf growth equations with typical data for 'LB9506' under HTHL and treated with 333 mgL^{-1} fertilizer rate are presented as follows:

1. The monomecular equation

$$L_1 = 0.9539 + 20.7233\,(1-\exp(-0.0139t)) \quad (15)$$

$R^2 = 0.9968$, s = 0.182

2. The logistic equation

$$L_2 = \frac{10.8127}{1+\exp(-0.09964(t-19.8928))} \quad (16)$$

$R^2 = 0.9993$, s = 0.1181

3. The Gompertz equation

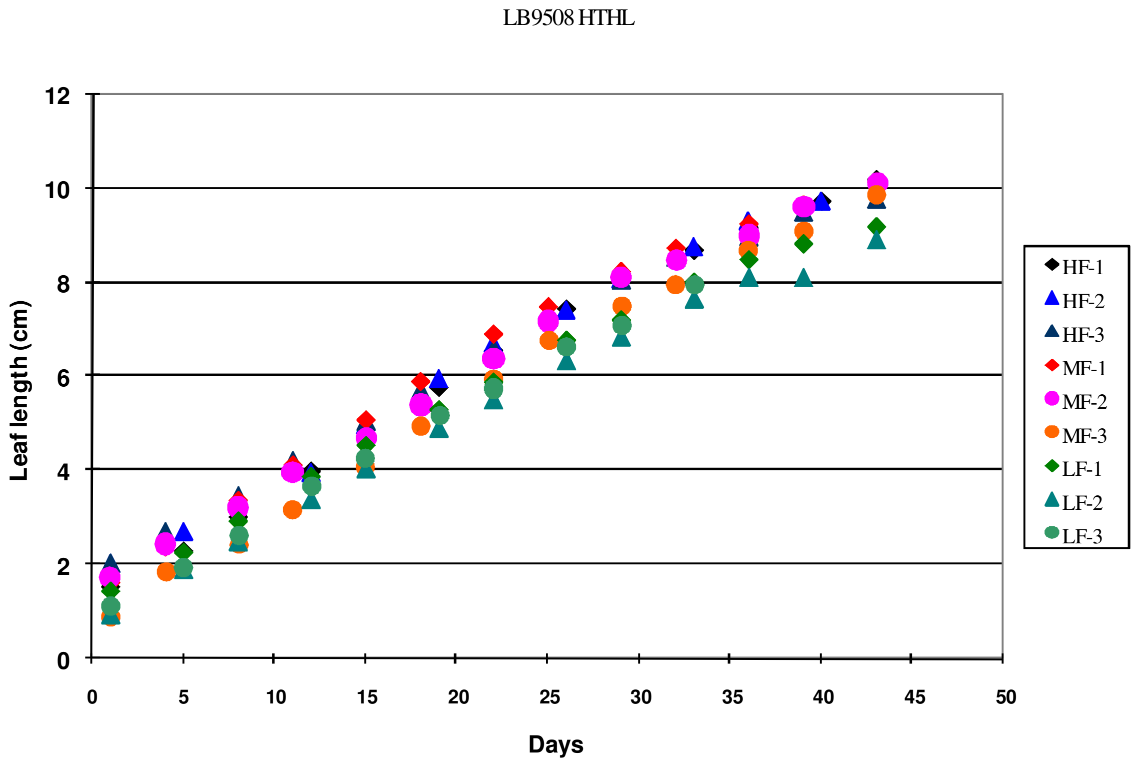

Figure 1. Representative leaf-length growth curves for *Phalaenopsis* 'LB9506' with three fertilizer rates (high, medium, low; H, M, L, respectively) under high temperature and high light intensity (HTHL).

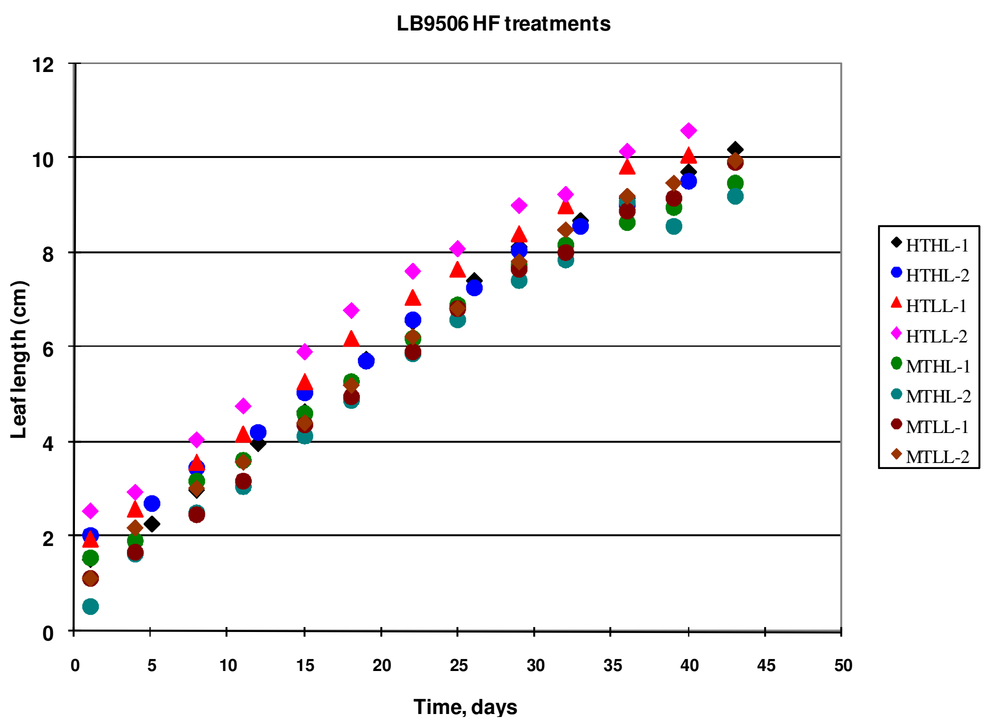

Figure 2. Representative leaf-length growth curves for *Phalaenopsis* 'LB9506' treated with 333 mgL-1 (high fertilizer, HF) and under different environmental conditions. See text for abbreviations.

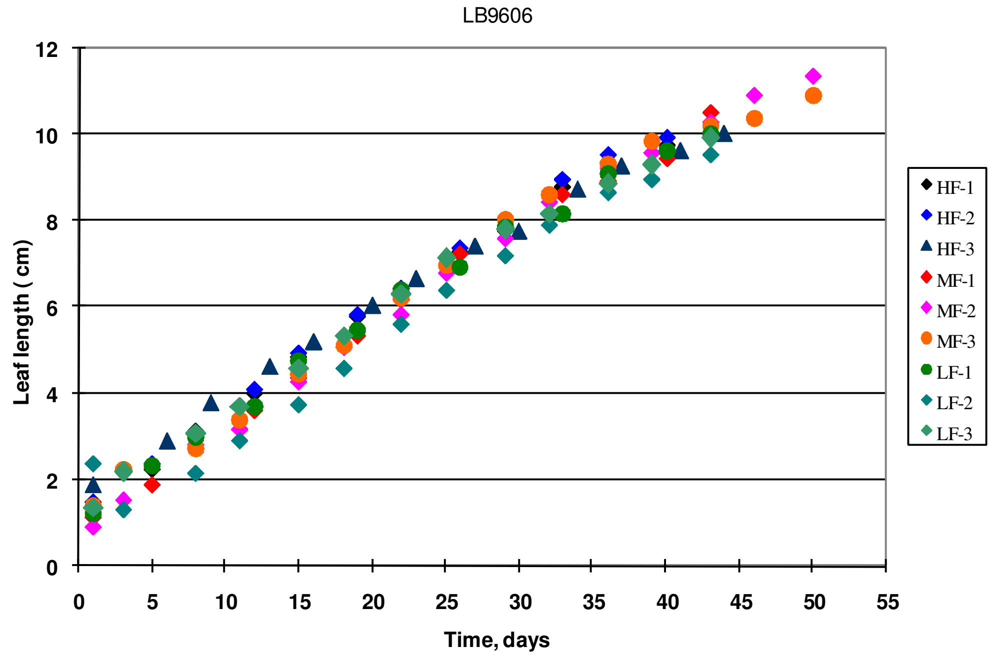

Figure 3. Representative leaf-length distribution of *Phalaenopsis* 'LB9508' with three fertilizer rates under high temperature and high light intensity (HTHL).

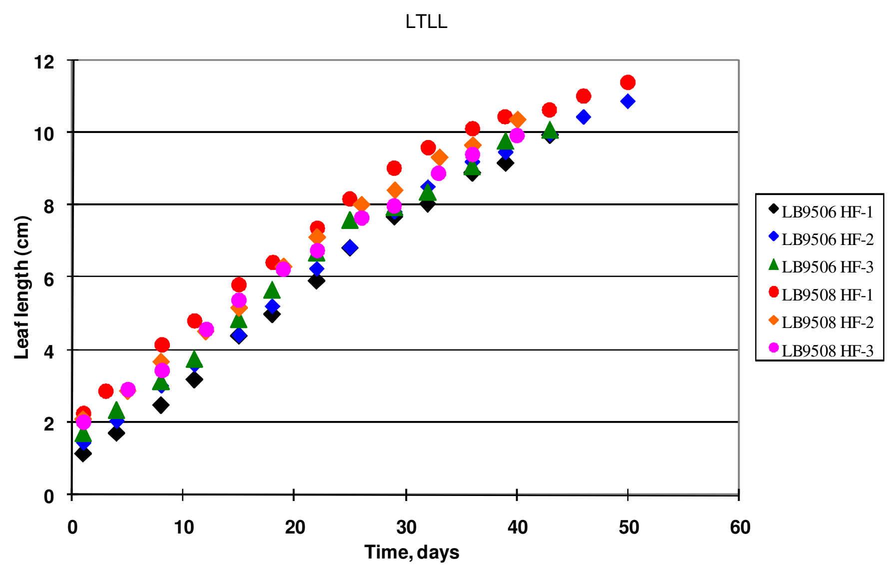

Figure 4. The leaf-length growth curves for the two varieties treated with 333 mgL-1 and under low temperature and low light intensity (LTLL).

$$L_3 = 12.2453 \exp(-\exp(\frac{t-14.0358}{17.4066})) \quad (17)$$

$R^2 = 0.9997$, s = 0.1065

All three equations had uniform distribution of data sets for residual plots. With the experimental design including four environmental conditions and three fertilizer rates, with each treatment involving ten replicates, the total data sets were 120 samples. Some typical estimated parameters and evaluated criteria are listed in Tables 1, 2 and 3.

Data analyzed by the logistic equation produced most of the largest R^2 and smallest s values; therefore, the

Table 1. The estimated parameters and evaluation criteria of three leaf-length growth equations for *Phalaenopsis* 'LB9506' with two fertilizer rates under high temperature and high light intensity.

Fertilizer rate		333 mgL^{-1}			167 mgL^{-1}		
Equation		Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3
1. Monomecular							
	L_{f1}	0.9539	1.5412	1.6117	1.0324	0.5799	0.7157
	a_1	20.7233	29.3247	17.5494	18.3176	17.9685	18.1958
	b_1	0.0139	0.0085	0.0152	0.0142	0.0146	0.0148
	R^2	0.9968	0.9976	0.9986	0.9992	0.9988	0.9992
	s	0.182	0.2051	0.1524	0.1117	0.1585	0.1142
2. Logistic							
	L_{f2}	10.8127	11.0300	10.7243	9.9922	9.3633	9.7513
	b_2	0.099637	0.089786	0.088431	0.093727	0.102824	0.10017
	x_0	19.8928	17.4698	16.4427	17.7303	18.3283	18.1140
	R^2	0.9993	0.9993	0.9992	0.9994	0.9945	0.9992
	s	0.1181	0.1087	0.0812	0.1115	0.1623	0.1160
3. Gompertz							
	a_3	12.2453	13.0289	12.1060	11.3121	10.5645	10.9824
	b_3	17.4066	20.2432	19.2304	18.3075	16.7701	17.1022
	c_3	14.0358	14.1870	12.1459	13.784	14.4912	14.1609
	R^2	0.9997	0.9991	0.9993	0.9986	0.9914	0.9934
	s	0.1065	0.1299	0.0734	0.0923	0.1315	0.0912

Table 2. The estimated parameters and evaluation criteria of three leaf-length growth equations for *Phalaenopsis* 'LB9506' with two fertilizer rates under high temperature and low light intensity.

	333 mgL^{-1}			167 mgL^{-1}		
Equation	Sample.1	Sample.2	Sample 3	Sample 1	Sample 2	Sample 3
1. Monomecular						
L_{f1}	1.4939	1.7938	1.7505	1.1900	1.3187	1.9629
a_1	20.5526	16.3366	20.1313	19.3772	18.8036	17.8435
b_1	0.0141	0.0196	0.0148	0.0143	0.0149	0.0152
R^2	0.9968	0.9960	0.9975	0.9962	0.9968	0.9934
s	0.1726	0.1868	0.1589	0.1952	0.1788	0.2484
2. Logistic						
L_{f2}	11.0911	11.3051	11.5669	11.2572	11.3850	11.7754
b_2	0.09576	0.09558	0.092854	0.08762	0.08649	0.08031
x_0	16.1538	14.4319	15.6569	18.9282	18.5420	17.0853
R^2	0.9982	0.9966	0.9977	0.9972	0.9984	0.9975
s	0.1310	0.1806	0.1515	0.1679	0.1244	0.1521
3. Gompertz						
a_3	12.6523	12.5669	13.1408	12.6248	12.7294	13.1543
b_3	18.0926	17.2630	18.4433	19.3292	19.4474	20.7562
c_3	12.3637	10.2185	11.7111	14.4148	13.9255	12.1929
R^2	0.9980	0.9965	0.9984	0.9968	0.9980	0.9971
s	0.1333	0.1795	0.1370	0.1785	0.1264	0.1637

logistic equation performed better than other two equations for quantitative criteria. The parameters of the logistic equation were adopted for further analysis.

ANOVA of the parameters of the logistic equation

Two parameters of the logistic equation, L_{f2} and b_2 were

Table 3. The estimated parameters and evaluation criteria of three leaf-length growth equations for *Phalaenopsis* 'LB9508' with three fertilizer rates under high temperature and high light intensity.

Fertilizer rate	333 mgL^{-1}			250 mgL^{-1}			167 mgL^{-1}			333 mgL^{-1}		
Equation	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3
1. Monomecular												
L_{f1}	0.9501	1.0746	1.5430	0.6176	0.6084	0.9189	0.9170	0.1466	1.1376	1.4939	1.7938	1.7505
a_1	23.7514	29.0672	19.4124	27.1263	33.4389	21.7478	22.5697	26.7864	21.3827	20.5526	16.3366	20.1313
b_1	0.0119	0.0094	0.0133	0.0104	0.0081	0.0129	0.0122	0.0103	0.0125	0.0141	0.0196	0.0148
R^2	0.9983	0.9983	0.9992	0.9976	0.9980	0.9953	0.9970	0.9916	0.9971	0.9968	0.9960	0.9975
s	0.1131	0.1204	0.1130	0.2305	0.1586	0.2410	0.1721	0.1962	0.1680	0.1726	0.1868	0.1589
2. Logistic												
L_{f2}	10.7428	11.1428	11.0831	10.9083	11.6691	11.4579	10.8374	10.0333	10.6050	11.0911	11.3051	11.5669
b_2	0.09858	0.09607	0.08246	0.10236	0.09414	0.09379	0.09447	0.11375	0.09488	0.09576	0.09558	0.092854
x_0	17.7855	18.3142	17.9621	19.3899	21.5852	20.1283	18.8402	19.931	17.9644	16.1538	14.4319	15.6569
R^2	0.9978	0.9985	0.9987	0.9972	0.9987	0.9993	0.9968	0.9941	0.9967	0.9982	0.9966	0.9977
s	0.1203	0.1149	0.1161	0.2509	0.1571	0.129	0.1532	0.1582	0.1778	0.1310	0.1806	0.1515
3. Gompertz												
a_3	12.3514	13.0147	12.5762	12.5640	13.5713	12.9089	12.3939	11.4840	12.1556	12.6523	12.5669	13.1408
b_3	17.6503	18.6862	20.6243	17.4632	19.2476	18.6442	18.4894	15.8088	18.5995	18.0926	17.2630	18.4433
c_3	14.2412	14.9664	13.5274	15.9116	17.9732	15.8138	14.9942	16.5779	14.1632	12.3637	10.2185	11.7111
R^2	0.9972	0.9979	0.9952	0.9984	0.9975	0.9985	0.9966	0.9974	0.9961	0.9980	0.9965	0.9984
s	0.1244	0.1151	0.1182	0.1927	0.1799	0.1903	0.1853	0.1322	0.1823	0.1333	0.1795	0.1370

adopted to evaluate the factors affecting leave growth characteristics. The biological meaning of L_{f2}, termed Y_{max} hereafter, is the growth limitation or the maximal of the leaf-length. The b_2 value represents the growth rates of leaf-length.

Variety 'LB9506'

The effect of environmental conditions and fertilizer rates on the parameters of the logistic equation for "LB9506" is showed in Figure 5.

From the two-way ANOVA test, the maximal leaf-length, Y_{max} significantly differed between the fertilizer rate ($F(2, 108) = 18.1606$, $P < 0.0001$), environmental conditions ($F(3, 108) = 66.4215$, $P < 0.0001$) and by the interaction of fertilizer rates and environmental conditions ($F(6, 108) = 4.666$, $P=0.0003$). Therefore, fertilizer rate, environmental conditions and their interaction all had a significant effect on the leaf-length growth of 'LB9506' (Figure 5a).

The Tukey's post-hoc LSD analysis revealed the Y_{max} with 167 mgL^{-1} fertilizer rate significantly lower than that with the other two treatments, with no significant effect with 333 and 250 mgL^{-1} fertilizer rates on the leaf growth.

The Tukey's post-hoc LSD test revealed the Y_{max} highest with the HTHL and HTLL conditions. The high temperature factor influenced the maximal length of leaves.

Analysis of leaf-length growth rate, b_2 revealed a significant effect of environmental conditions ($F(3, 108) = 2.9461$, $P=0.036$) but not fertilizer rate ($F(2, 108) = 1.5619$, $P=0.2144$) or interaction of fertilizer rate and environmental conditions ($F(6, 108) = 1.4937$, $P=0.1837$) (Figure 5b).

Further analysis by the Tukey's test revealed three different groups of b_2 values, for HTHL, HTLL and LTHL, LTLL. The growth rate was largest with HTHL.

Variety 'LB9508'

The effect of environmental conditions and

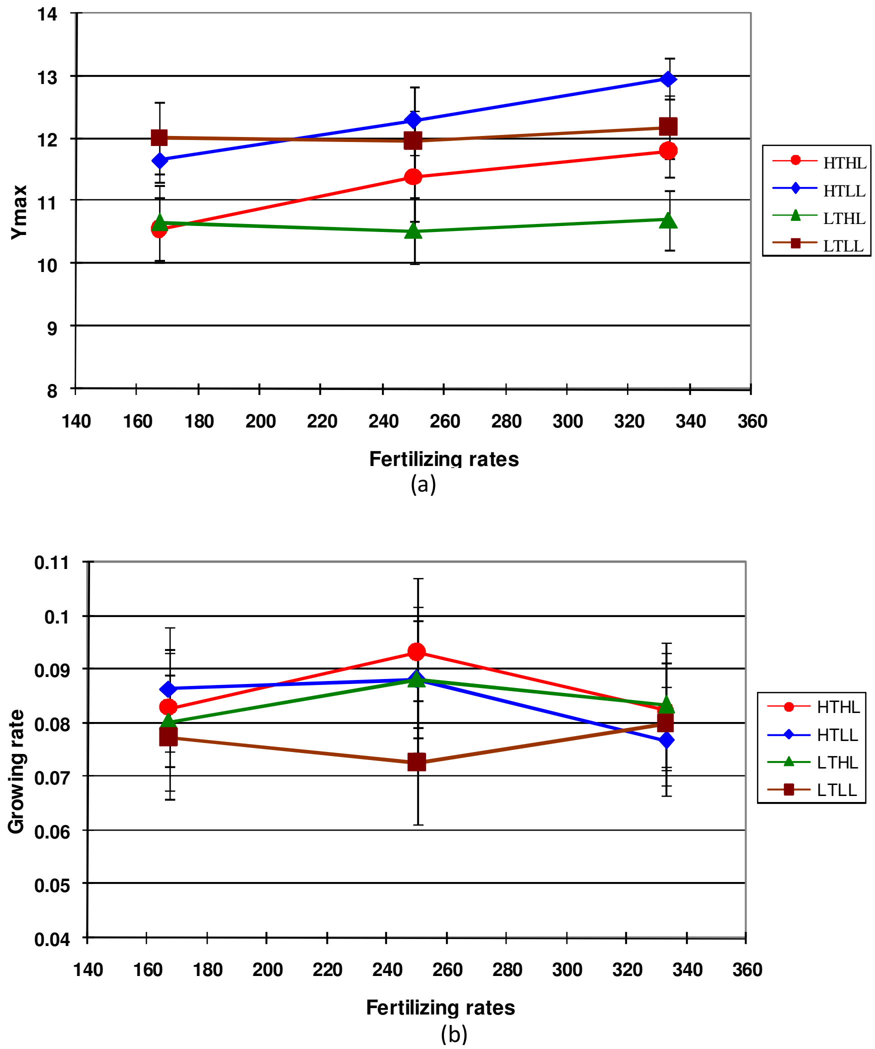

Figure 5. The effect of environmental conditions and fertilizing rates on the parameter of the logistic equation for 'LB9506'.

fertilizer rates on the parameters of the logistic equation for 'LB9508' is shown in Figure 6.

The maximal leaf-length, Y_{max} for 'LB9508' differed by fertilizer rates ($F(2, 108) = 5.97$, $P=0.0035$) and the environmental conditions ($F(3, 108) = 56.07$, $F < 0.0001$). However, the interaction of both factors was not significant ($F(6, 108) = 0.6993$, $P=0.6508$) (Figure 6a).

The Tukey's test revealed the Y_{max} with the lowest fertilizer rate, 167 mgL^{-1}, significantly lower than with other two treatments, with no significant difference between 333 and 250 mgL^{-1} fertilizer rates.

The Tukey's test also revealed a significant difference among the four environmental conditions. The Y_{max} for LTHL was larger than for the other conditions.

Analysis of leaf-length growth rate, b_2 values revealed no significant difference between the fertilizer rates ($F(2, 108) = 1.0981$, $P=0.3372$), environmental conditions ($F(3,108) = 0.7344$, $P=0.5337$) or their interaction ($F(6, 108) = 1.2991$, $P=0.2638$).

The leaf-length growth rate for 'LB9608' was similar with fertilizer rates from 167 to 333 mgL^{-1}, day temperature from 23 and 30°C, and light intensity from 150 to 280 µmol $m^{-2}s^{-1}$. However, the maximal leaf-length for this variety was affected by day temperature and light intensity.

By combination of best growth conditions and fertilizer dosage, 45 days could be reduced to unfold one leaf. This data could be more meaningful and realistic to orchid growers.

DISCUSSION

Effect of day temperature and light intensity

Lopez and Runkle (2003) reported on influence of

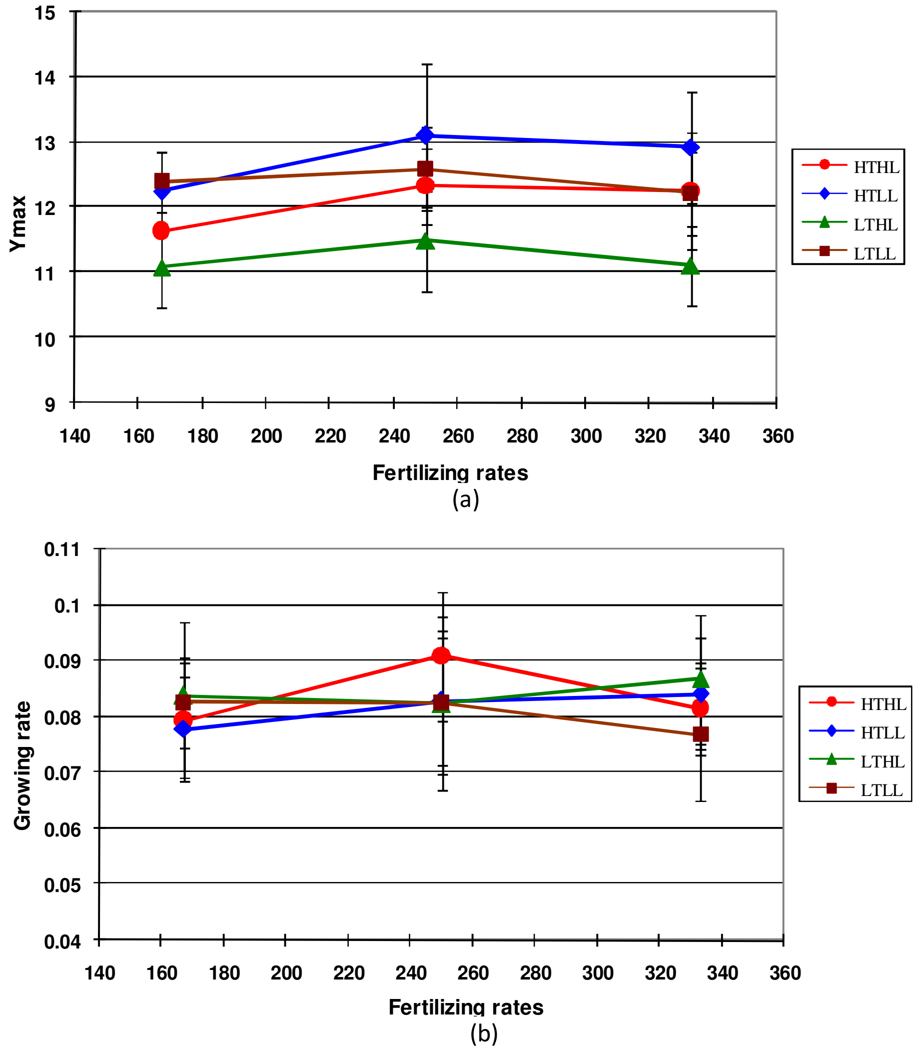

Figure 6. The effect of environmental conditions and fertilizing rates on the parameters of the logistic equation for 'LB9508'.

temperature on leaf growth in *Zygopetalum* Redvale 'Fire Kiss' by averaging the data points in their growth curves for the 20 plants. However, the effect of the variation for each plant at different culture days could not be estimated statistically. In this study, the growth data for leaf-length for each plant was analyzed using nonlinear regression technique. Each plant had a numeric value for each parameter, with the best-fit equation, the logistic equation. These parameters were further analyzed to observe the significant effect of influencing factors.

Environmental conditions had a significant effect on the maximal leaf-length (Y_{max}) for the two varieties. For 'LB9606' but not 'LB9608', the growth rate (b_2) was affected significantly by environmental conditions. Other researchers have reported on the effect of temperature and light intensity on the growth of orchids. Kubota and Yoneda (1990) found that *Phalaenopsis* grew better under 30°C than 20°C. Kaziwara et al. (1992) found that *Phalaenopsis* had a better growth rate under day and night temperatures of 30/25°C than 25/20°C. Ota et al. (1991) reported an optimal day and night temperature of 25/15°C than at 25/20 and 20/20°C.

Differences in recommended light intensity were found. The point of light saturation for 'Watabousbi' was 130 (Ota et al., 1991) and 180 μmol m^{-2} s^{-1} for 'L' and '70' at 20°C (Lootens and Heursel, 1998). The adequate light level was found to range from 150 to 330 μmol m^{-2} s^{-1} (Konow and Wang, 2001). These results support the finding of good effects with low light, 150-210 μmol m^{-2} s^{-1}. The effect of environment conditions on the growth characteristics at different varieties was inconsistent.

Effect of fertilizer rate

The results of this study revealed that the fertilizer rate had a significant effect on maximal leaf-length for two varieties. However, the growth rates were not significantly different with the different fertilizer treatments. Wang and Gregg (1994) found that fertilizer level had a significant effect on stalk diameter, stalk length and leaf production of *Phalaenopsis*. In a study of the effects of six fertilizers on vegetative growth of *Phalaenopsis*, Wang (1996) found that high fertilizer concentrations produced more and longer leaves and greater total leaf areas. Orchids grown in moss sphagnum showed wider and longer top leaves with increased potassium concentration (Wang, 2007). These results agree with the results of this study that high fertilized rate increased the maximal leaf-length of two varieties.

The effect of the environment on the growing rate needs to be studied for more varieties to understand the mechanism of temperature, light and fertilizer on the leaf growth on *Phalaenopsis.* The open-system chamber could be adopted to reduce the experimental space (Alterio et al., 2006).

Further study of the growth equation

The effect of environmental conditions and fertilizer rates on the growth characteristics of orchids was previously reported (Anthura, 2004, 2005; Lopez and Runkle, 2003; Bichsel et al., 2008). The effect of temperature and nitrogen level on vegetative and reproductive phase in *Cymbidium* orchids were discussed by Powell et al. (1988). Pan et al. (1997) reviewed the physiology of *C. sinense* including the photosynthesis, mineral nutrition, growth and development and suggested the detailed study of the orchids. The growth characteristic curves of the orchids, such as leaf-length, leaf area, bulb length and diameter, stalk length in different conditions could be measured and analyzed by using an adequate nonlinear growth equation. The parameters then were studied to evaluate the significant factors affecting the growth characteristics. This analysis could provide a powerful method to quantify the influencing factors.

Conclusions

The leaf-length growth patterns of two *Phalaenopsis* varieties, the red-flower *Phalaenopsis* clones ‘LB9506’ and ‘LB9508’ were measured under different environmental conditions; day temperature, light intensity, and fertilizer rates. Three nonlinear growth equations for evaluating leaf-length data of two varieties were studied and the parameters of the best-fit equation for biological interpretation were further analyzed.

From the results of this study, an adequate growth equation is useful for evaluating factors affecting plants growth characteristics. The measurement data of the leaf-length at different culture days in different conditions were analyzed by growth equations. The parameters of the fitting growth equation could by further studied using the ANOVA. With this method, the factors affecting the growth characteristics of orchid leaves were evaluated quantitatively and the variation in each plant by growth characteristics could be explained statistically. Other indexes of the plant, such as stem length and dry or fresh weight could also be analyzed by this method.

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