American-Eurasian J. Agric. & Environ. Sci., 3 (6): 888-892, 2008
ISSN 1818-6769

A Growth Curve Application to Compare Plant Heights and Dry Weights of Some Wheat Varieties

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Abstract: In this study, plant height and plant dry weight of five wheat varieties (namely Da–daÕ 94, K2nac2 97, Konya 2002, Karahan 99 and Ahmeta–a), collected for 20 weeks, were modeled via fitting generalized logistic (GLC), logistic (LC) and Gompertz (GC) growth curves. Growth curve selection was based on residual sum of square (RSS) and mean square error (MSE). Following growth curve selection, growth curves of wheat varieties and their parameter estimates were compared via a sum of square reduction test. Results from growth curve fitting show that GLC and LC produced similar RSS and MSE values while GC resulted in higher RSS and MSE values both for plant height and dry weight. Since parameters of LC have meaningful biological interpretation, it was chosen for plant height and dry weight modeling. Results from the sum of square reduction test show that Ahmeta–a has the highest plant height potential (124.3 cm) while the varieties Konya 2002 and Karahan 99 have the smallest (102.6 cm). Konya 2002 is the variety that reaches maximum absolute growth rate earliest (9.29 weeks) while Karahan 99 reaches it latest (10.37 weeks). Asymptotic dry weight of all wheat varieties was found to be 43.27 g. Results also show that all varieties reaches to maximum growth rate at 14.89 weeks, except the variety Konya 2002 that reaches the same stage at 14.03 weeks.

Key words: Logistic curve % Gompertz curve % Generalized logistic curve % Comparison of growth curves of wheat varieties % Sum of square reduction test

INTRODUCTION

Growth is one of the important properties of living organisms. Changes in a phenotype during the growth period can be modeled via growth curves, such as generalized logistic, logistic or Gompertz growth curves. Behavior of the growth curves can change according to living organisms, the phenotype to be studied and environment to which it is exposed. To be able to evaluate growth data properly, it is required to select a suitable growth curve and its parameters should be able to be interpreted biologically.

In the past, models have been developed to describe and explain the growth and yield of plants both for glasshouse conditions [1-4] and for field experiments [5-10].

Von Fircks and Verwijst [11] used the logistic and the Richards functions to model frost resistance of plant shoots. Tadesse *et al*. [12] used the logistic growth curve to model leaf area development of potato plants. Hara [13] used the Richards and logistic functions to model germination data of several rice varieties.

Karadavut [14] used the Richards, logistic, Gompertz and Weibull growth curves for fresh weight of rye plant which was grown in the Konya conditions. Karadavut *et al*. [15] used 10 different models in a study to evaluate growth of DagdaÕ wheat plant in different sowing frequencies (450, 550 and 650 plants m^{-2}). Karadavut and Kay2Õ [16] used a Gompertz growth curve to compare fresh weight of some wheat varieties.

This study reports on a comparison of growth curves of plant height and plant dry weight of five wheat varieties that are commonly growth in Konya area. The aims of this study are: 1) to determine a suitable growth curve for plant height and plant dry weight data; and 2) to compare plant height and plant dry weight of wheat varieties via the selected growth curve.

MATERIALS AND METHODS

In this study was carried out in 2004-2005 years. Plant height and dry weight of five wheat varieties (namely Da–daÕ 94, K2nac2 97, Konya 2002, Karahan 99 and Ahmeta–a), which are widely growth in Konya region,

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Turkey, were used. Phenotypes were recorded in weekly for twenty weeks starting from emergence. Measurements were used 5 plants given each plot and each variety. The experiment was conducted at the Bahri Da–daÔ International Agricultural Research Institute and Soil and Water Research Institute as two locations in Konya, Turkey. The field plots used was allocated in a complete randomized design (CRD) with five replicate plots per variety [17].

Changes in the plant height and dry weight of the five wheat varieties were modeled via generalized logistic (GLC), Gompertz (GC) and logistic curves (LC). The functions of GLC, GC and LC are given in (1), (2) and (3), respectively.

$$Y_{ij} = A + \frac{C}{\left(1 + Te^{-B(X_i - M)}\right)^{1/T}} + e_{ij} \tag{1}$$

where

Y_{ij} = Phenotype of j^{th} experimental unit in the i^{th} recording time,

A = Constant (in this study, it is set to 0, $A = 0$),

C = Final or potential yield,

T = Near which asymptote maximum growth occurs ($T > 1$ near top, $T < 1$ near bottom, $T = 1$ normal),

B = Relative growth rate,

X_i = i^{th} recording time,

M = Time at which absolute growth rate is maximum,

e_{ij} = Residual term for j^{th} experimental unit at i^{th} recording time.

$$Y_{ij} = A + Ce^{-e^{-B(X_i - M)}} + e_{ij} \tag{2}$$

where, Y_{ij}, X_i, A, C, e and e_{ij} are as in (1),

M = Time at which absolute growth rate is maximum; this is also the time at which the relative growth rate is B and the time at which growth has reached $e^{-1}C$; note that $e^{-1} = 0.368 - 1/3$,

B = Relative growth rate at time = M,

$$Y_{ij} = A + \frac{C}{1 + e^{-B(X_i - M)}} + e_{ij} \tag{3}$$

where, Y_{ij}, X_i, A, C, e and e_{ij} are as in (1).

M = Time at which absolute growth rate is maximum; Time at which relative growth rate is ½B; Time at which growth has reached ½C,

B = Twice the relative growth rate at time = M; Approximately the relative growth rate at time = 0

Of these curves, the parameters of LC and GC have a simple biological interpretation. On the other hand, GLC has an additional parameter (T) which makes it more flexible. Unfortunately, the addition of the parameter T affects the simple biological interpretability of the parameters of the model [18].

Model fitting and parameter estimation were performed via the PROC NLIN procedure of SAS [19].

In order to determine the best fitting growth curve, models were fitted with separate parameters for each variety and common parameters for all varieties via GLC, LC and GC. Selection of the best fitting growth curve was done based on the residual sum of square (RSS) and the mean square error (MSE). However, when the comparison is made between GLC versus LC or GC, results of MSEs were primarily considered since it takes into account the number of parameters in the model as well.

Following determination of the suitable growth curve, a full model, which has different parameters set for each variety and a reduced model, which has common parameters for varieties were fitted. Full and reduced models were compared via a sum of square reduction test (4) according to Draper and Smith [20].

$$F_{D,Rdf_F} = \frac{\left(RSS_R - RSS_F\right)/D}{MSE_F} \tag{4}$$

where,

RSS_R = Residual sum of square for reduced model,

RSS_F = Residual sum of square for full model,

D = Rdf_R - Rdf_F, where

Rdf_R = Residual degrees of freedom for reduced model,

Rdf_F = Residual degrees of freedom for full model,

MSE_F = Mean square error for full model,

$F_{D,RdfF}$ = F value with D and Rdf_F degrees of freedom.

RESULTS AND DISCUSSION

Growth Curve Selection: Results from growth curve fitting of GLC, LC and GC to plant height data are summarized in Table 1. As it can be seen from Table 1, GLC has the smallest RSS for growth curve fitting via both common and separate parameters (17684.5 and 3021.2, respectively) while the GC has the largest RSS for growth curve fitting via both common and separate parameters (19747.1 and 5229.1, respectively). On the other hand, the RSS of LC for common and separate parameters (17689.5 and 3145.7, respectively) were close to those of GLC.

Table 1: Results from growth curve fitting of GLC, LC and GC to plant height data

Growth Curve	No. of parameters in curve	Growth curve fitting via: Common parameters RSS	MSE	Separate parameters RSS	MSE
GLC	4	17684.5	35.65	3021.2	6.29
LC	3	17689.5	35.59	3145.7	6.48
GC	3	19747.1	39.73	5229.1	10.78

Table 2: Results from growth curve fitting of GLC, LC and GC to plant dry weight data

Growth Curve	No. of parameters in curve	Growth curve fitting via: Common parameters RSS	MSE	Separate parameters RSS	MSE
GLC	4	1405.9	2.83	1020.9	2.13
LC	3	1424.2	2.87	1043.3	2.15
GC	3	1469.9	2.96	1092.8	2.25

Table 3: Comparison of full and reduced models for plant height of wheat varieties via the sum of square reduction test

Variety	Parameters: *B*±S.E.	*C*±S.E.	*M*±S.E.
Da–daÕ 94	0.37±0.0035	110.9±0.5495	9.63±0.0453
K2nac2 97	0.37±0.0035	107.4±0.5414	9.63±0.0453
Konya 2002	0.37±0.0035	102.6±0.4953	9.29±0.0594
Karahan 99	0.34±0.0057	102.6±0.4953	10.37±0.0623
Ahmeta–a	0.37±0.0035	124.3±0.6478	9.99±0.0556

When the fitted growth curves were compared using MSE for the common parameters, it is seen (Table 1) that LC has the lowest value (35.59) while the GC has the largest value (39.73). However, when a comparison was made according to separate parameters for each variety, GLC has the lowest MSE (6.29) while GC has the highest MSE (10.78). Since LC fits as well as GLC and its parameters have a simple biological interpretation, it was chosen for the comparison of plant height of wheat varieties.

Results from growth curve fitting of GLC, LC and GC to plant dry weight data are summarized in Table 2. Evaluation of Table 2 shows that GLC has the smallest RSS and MSE in fitting common parameters across all varieties (1405.9 and 2.83, respectively) and in separate parameter fitting (1020.9 and 2.13, respectively) while GC has the largest RSS and MSE in common parameter fitting (1469.9 and 2.96, respectively) and in separate parameter fitting (1092.8 and 2.25, respectively). However, MSEs of LC for common and separate parameters model fitting (2.87 and 2.15, respectively) were similar to those of GLC. Therefore, LC was chosen for the comparison of plant dry weight of wheat varieties.

Variety Comparison: Height: Comparison of full and reduced models for plant height of wheat varieties via the sum of square reduction test showed that it is not possible to express the growth curve of plant height for the five wheat varieties via a single parameters set ($P < 0.01$), but can be modeled via sharing some of the parameters (Table 3). Results show that Da–daÕ 94, K2nac2 97, Konya 2002 and Ahmeta–a varieties can be modeled with the same *B* (0.37 weeks). However, the estimated parameter *B* of the variety Karahan 99 (0.34 weeks) was found to be statistically significant from the estimated *B*s of other varieties. Konya 2002 and Karahan 99 varieties have the same estimated *C* (102.6 cm) parameters. Da–daÕ 94 and K2nac2 97 have the same estimated parameter *M* (9.63 weeks). It can be seen from Table 3 that the variety Ahmeta–a has the highest height potential (124.3 cm) while the varieties Konya 2002 and Karahan 99 have the smallest height potential. Konya 2002 is the first variety that reaches maximum absolute growth rate (9.29 weeks) while Karahan 99 reaches this latest (10.37 weeks). These are also the time at which varieties have reached half of their final yield. Observed plant height and fitted values via LC for wheat varieties are shown in Figure 1.

Variety Comparison: Dry Weight: Comparison of full and reduced models, for plant dry weight of wheat varieties, via a sum of square reduction test showed that it possible to express the growth curve of plant dry weight of all varieties via a single parameter set except the variety Karahan 99. Karahan 99 differs from other varieties only with the parameter *M* (estimated at 14.03 weeks). Parameter estimates are summarized in Table 4. Results show that asymptotic dry weight of wheat varieties found to be 43.27 g. Results also show that all varieties reach maximum growth rate at 14.89 weeks, except the variety Konya 2002 that reaches this at 14.03 weeks. Observed plant dry weight and fitted values via LC for wheat varieties are given in Figure 2. According to our best knowledge, there are no other studies on these wheat varieties which have investigated their growth curves. Therefore, it is not possible to compare our results with another study.

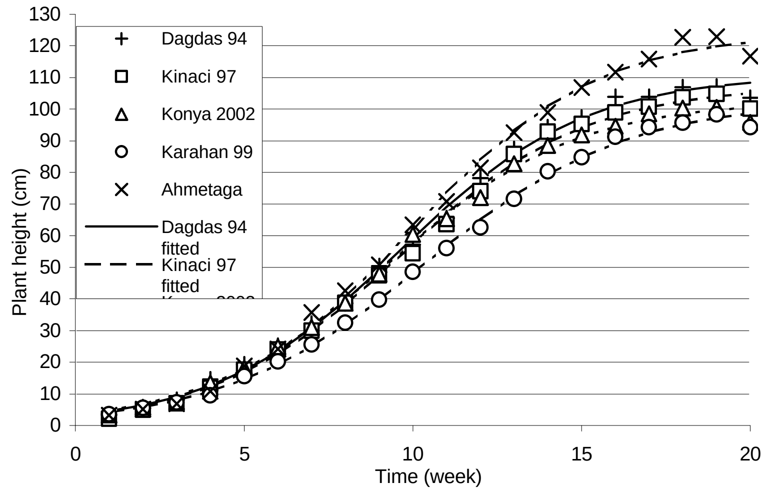

Fig. 1: Observed plant height and fitted values via LC for wheat varieties

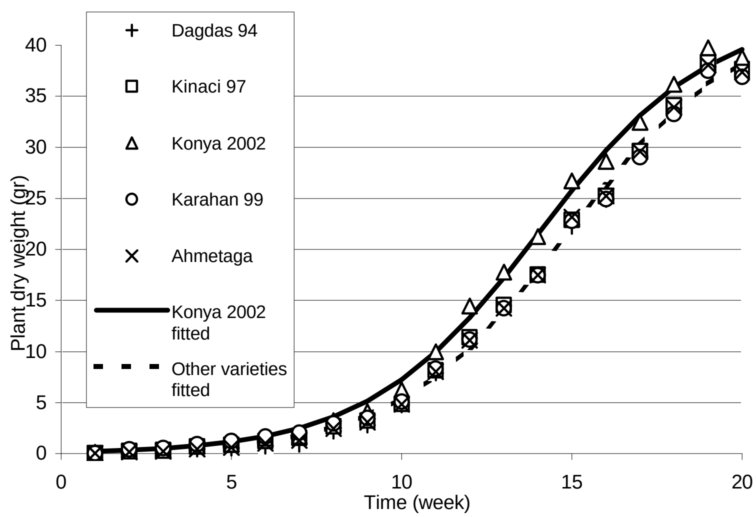

Fig. 2: Observed plant dry weight and fitted values via LC for wheat varieties

Table 4: Comparison of full and reduced models, for plant dry weight of wheat varieties, via a sum of square reduction

Variety	Parameters *B*±S.E.	*C*±S.E.	*M*±S.E.
Da–da0̂ 94	0.40±0.0072	43.27±0.5002	14.89±0.0814
K?nac? 97	0.40±0.0072	43.27±0.5002	14.89±0.0814
Konya 2002	0.40±0.0072	43.27±0.5002	14.03±0.0978
Karahan 99	0.40±0.0072	43.27±0.5002	14.89±0.0814
Ahmeta–a	0.40±0.0072	43.27±0.5002	14.89±0.0814

Growth curves show the changes in the growth according to time. In this study, growth curves for wheat varieties were evaluated. It is known that the fast growing period is the time that the formation of a plant's tillers and bolting occur. During this period, plants require more nutrients. In practice, knowing this period in advance is vitally important since it is the time for some management such as irrigation and fertilization application. In addition, results from well-fitting growth curves for wheat varieties allows estimating critical time points. Consequently, farmers can perform the necessary management at the optimally chosen time. Therefore, results from this study would be helpful to farmers for this type of application.

CONCLUSION

In this study, growth curves were fitted to plant height and plant dry weight data and it was found that both phenotypes could be modeled via LC. In terms of plant height, most of the wheat varieties were statistically significantly different from each other with regards to potential yield and the time at which maximum absolute growth rate occur. However, in terms of plant dry weight, only one variety differs significantly from others only for the time at which maximum absolute growth rate occurs.

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