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Research Article

Height-age growth curve modelling for different multipurpose tree species in drylands of north Karnataka

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Abstract : Among 12 multipurpose tree species tested for height and age relationship under agroforestry systems of northern dry zone of Karnataka, Gompertz model and Weibull model fitted well for 4 species each, Exponential model for 3 species and only one species showed its fitness to Richards model. Among the different models tried in predicting height growth, Gompertz model was well fitted to Acacia nilotica (R^2 = 0.9981), Bahunia purpurea (R^2 = 0.9971), Inga dulce (R^2 = 0.9968) and Tamarindus indica (R^2 = 0.9968). Where as, Weibull model fit well for Leucana leucocephala (R^2 = 0.9987), Dalbergia sissoo (R^2 = 0.9978), Eucalyptus citriodara (R^2 = 0.9982) and Pongamia pinnata (R^2 = 0.9991). Hence, Gompertz model can be best adopted while predicting height growth of native species grown under dry land situation.

Key Words : Height, Age, Model, Species, Multipurpose

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INTRODUCTION

Tree height and diameter relationship is an important component in yield estimation, stand description, and damage appraisals (Parresol, 1992). Many height and diameter equations have been developed for various tree species (Wykoff *et al.,* 1982; Huang *et al.,* 1992). Among the variety of mathematical equations, sigmoidal or non-linear growth functions are widely used in developing tree height and diameter equations. Foresters often use height-diameter models to predict total tree height (c-I>) based on observed diameter at breast height (DBH) for estimating tree or stand volume and site quality. Therefore, estimations of tree or stand volume and site quality rely heavily on accurate height-diameter functions. There is no standard height/age relationship for trees because of the influence of both internal and external factors on height growth but the basic pattern is sigmoidal.

Growth models assist forest researchers and managers in many ways. Some important uses include the ability to predict future yields and to explore silvicultural options. Models provide an efficient way to prepare resource forecasts, but a more important role may be their ability to explore management options and silvicultural alternatives. For example, foresters may wish to know the long-term effect on both the forest and on future harvests of a particular silvicultural decision, such as changing the cutting limits for harvesting. With a growth model, they can examine the likely outcomes, both with the intended and alternative cutting limits, and can make their decision objectively. The process of developing a growth model may also offer interesting and new insights into the forestry. Growth models may also have a broader role in forest

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management and in the formulation of forest policy. The same could be used as an advantage and in conjunction with other resource and environmental data, to make prediction, formulate prescriptions and guide forest policy decisions into stand dynamics. Hence, looking to the importance of growth models in forestry, the present study was carried out to develop growth models for different multipurpose trees under dryland conditions of north Karnataka.

EXPERIMENTAL METHODS

The experiment was conducted at Regional Agricultural Research Station, Bijapur of University of Agricultural Sciences, Dharwad, Karnataka from 1990-2000. The soils of the experimental site were analyzed for various physico-chemical properties (Sand 25%, Silt 23%, Clay 52%, bulk density 1.43 g/cc, pH- 8.5, EC- 0.34 dSm^{-1}, $CaCO_3$ 18.5% and soil depth 30-35 cm). The average rainfall of the site is 594 mm with 39 rainy days. Twelve multipurpose tree species *Viz*., *Acacia nilotica, Leucaena leucocephala, Azadirachta indica, Bahunia purpurea, Dalbergia sissoo, Eucalyptus citriodara, Eucalyptus hybrid, Hardwickia binata, Inga dulce, Pongamia pinnata, Syzygium cumini* and *Tamarindus indica* were planted in 1990 in RARS Bijapur and data were collected at one year interval up to 2000. The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. The trees were planted at a spacing of 2m x 2m and examined for 11 consecutive years. For developing growth curves the average height (m) of trees was measured using marked poles were recorded.

Developing height growth curves for twelve multipurpose tree species was done by selecting five non-linear models to compare fitness of these models to data (Thornley and France, 2007). The rationality behind the use of these growth models lies in the fact that these models have some important parameters enabling to comment on the growth process.

1. Gompertz model	Y = a*exp (-exp(b^-cx)) where a, b, c are the parameters in the model.
2. Exponential model	Y=a*exp (-b/(x+c)) where a, b and c are the parameters.
3. Weibull model	Y = a(1-b*exp (-c*x^d)) where a, b, and c are the parameters.
4. Richards model	Y=a*(1-exp (b*x))^c where a, b and c are the parameters in the model y is age and X is diameter.
5. Korf model	Y=a*exp (-b*x^-c) where a, b and c are the parameters in the model

EXPERIMENTAL RESULTS AND ANALYSIS

Among the different models tried in predicting height growth of multipurpose trees *Acacia nilotica,* Gompertz model (R^2 = 0.9981) was found better. Likewise in case of *Bahunia purpurea* (R^2 = 0.9971), *Inga dulce* (R^2 = 0.9976) and *Tamarindus indica* (R^2 = 0.9968) Gompertz was found better. Where as, Weibull model was fit well for *Leucana leucocephala* (R^2 = 0.9987), *Dalbergia sissoo* (R^2 = 0.9978), *Eucalyptus citriodara* (R^2 = 0.9982) and *Pongamia pinnata* (R^2 = 0.9991). Followed by exponential model for *Eucalyptus hybrid* (R^2 = 0.9933), *Hardwickia binata* (R^2 = 0.9991) and *Syzygium cumini* (R^2 = 0.9927). However, Richards model was found fit for *Azadirachta indica* (R^2 = 0.9989) (Table 1 and Fig. 1).

Among 12 multipurpose tree species tested for height and age relationship Gompertz model fitted well for 4 species showing faster early growth but slower approach to asymptote with a longer linear period about inflection point (Thornley and France, 2007). Arid conditions of the experimental site might also impart such slow approach to the asymptote. Weibull model better fitted for 4 species with highest R^2 and lesser standard error and parameters with asymptote t-values. But overall performance of model is better in which all models were showed R^2 between 0.98 and 0.99. Despite considering initial years of growth of all tree species which are characterized by exponential growth period, the exponential model did not show robustness in predicting in all species. Somez (2008) also reported that Gompertz model fit well in height estimation of *Picea orientalis.*

Among the five growth models tested in this study, Korf model showed least fit in almost every species hence considered to be least robust for all species. Among other four models, Gompertz model showed best fit with highest R^2 value and least standard error for 4 species. Interestingly the fast growing introduced species *Eucalyptus hybrid* showed best fit with respect to exponential model. Hence, it may be preliminarily concluded that Gompertz model can be best adopted while predicting height growth of native species. Mean prediction error, standard deviation and R^2 served the criteria for comparing model prediction performance of growth functions. In this Gompertz function showed superiority over other models for 4 species in height – age relationship followed by Weibull model (4 species).

Typically the asymptotic coefficient is the least stable parameter in non-linear growth functions. The least-squares of these growth functions may result in biologically unreasonable upper asymptotes, especially when there are few data observations near the asymptote. Extrapolation, using the models beyond the data range, may produce overestimation or underestimation for large-sized trees. To circumvent the problem some researchers constrained the growth functions by fixing the asymptote at a constant value, such as an available big tree record, while estimating all other parameters in the models (Brewer *et al.*, 1985, Zhang, 1997).

Table 1 : Comparison of the Observed values of DBH (cm) with that estimated by best-fit model and coefficient of determination, standard error, Mean Prediction Error (MPE), Standard Deviation (SD) with respect to multipurpose tree species under semi-arid regions of north Karnataka

Age (years)	Estimated values	Observed values	Growth model
T_1- *Acacia nilotica*			
1	0.900	0.48	Gompertz model
2	0.891	0.68	
3	1.549	1.23	
4	2.341	1.75	R^2=0.9981
5	3.187	2.71	
6	4.013	3.24	SE=0.0882
7	4.767	3.83	
8	5.420	4.40	MPE =-0.7304
9	5.967	4.70	
10	6.410	5.22	SD =0.4096
11	6.763	5.44	
15	7.541		Y=7.9211*exp
20	7.831		(-2.9119exp (-0.2918*X)
25	7.900		
30	7.916		
35	7.920		
40	7.921		
45	7.921		
50	7.921		
T_2- *Leucaena leucocephala*			
1	0.183	0.38	Weibull model
2	0.712	0.63	
3	1.536	1.66	
4	2.582	2.72	
5	3.764	3.81	
6	4.997	4.91	R^2=0.9987
7	6.200	5.72	
8	7.312	7.61	SE=0.1648
9	8.291	8.64	
10	9.114	9.20	MPE= 0.0372
11	9.777	9.60	
15	11.137		SD= 0.2358
20	11.444		
25	11.464		Y=11.465*(1-exp
30	11.465		(-0.0161*X^1.993))
35	11.465		
40	11.465		
45	11.465		
50	11.465		

Table 1 contd…

Contd… Table 1

Age (years)	Estimated values	Observed values	Growth model
T_3- *Azadirachta indica*			
1	0.083	0.340	Richards model
2	0.521	0.830	
3	1.271	1.260	
4	2.146	1.890	R^2=0.9989
5	2.995	2.530	
6	3.738	3.290	SE=0.0553
7	4.350	3.880	
8	4.834	4.210	MPE =-0.305522
9	5.206	4.560	
10	5.487	4.970	SD =0.33923
11	5.696	5.210	
15	6.108		Y=5.2672*(1-exp (-
20	6.236		0.3253*X)) ^3.3731
25	6.261		
30	6.266		
35	6.267		
40	6.267		
45	6.267		
50	6.267		
T_4- *Bahunia purpurea*			
1	0.493	0.640	Gompertz model
2	0.912	0.830	
3	1.445	1.485	
4	2.039	2.005	
5	2.639	2.510	R^2=0.99711
6	3.200	3.210	
7	3.698	3.760	SE=0.0943
8	4.120	4.190	
9	4.467	4.550	MPE =0.004599
10	4.745	4.710	
11	4.965	4.885	SD =0.08428
15	5.447		
20	5.626		Y=5.6821*exp
25	5.669		(-3.265*exp (-
30	5.679		0.4934*X))
35	5.681		
40	5.682		
45	5.682		
50	5.682		

Table 1 contd…

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Age (years)	Estimated values	Observed values	Growth model
T_5- *Dalbergia sissoo*			
1	0.360	0.520	Weibull model
2	0.902	0.850	
3	1.493	1.490	
4	2.077	2.010	
5	2.626	2.650	R^2=0.9978
6	3.123	3.130	
7	3.560	3.510	SE=0.0147
8	3.936	3.990	
9	4.255	4.310	MPE =-0.01784
10	4.519	4.420	
11	4.736	4.510	SD =0.09959
15	5.248		
20	5.458		
25	5.506		Y=5.5179*(1-exp (-
30	5.516		0.0675*X^-1.4036))
35	5.518		
40	5.518		
45	5.518		
50	5.518		
T_6- *Eucalyptus citriodara*			
1	0.760	0.790	Weibull model
2	1.769	1.760	
3	2.830	2.830	
4	3.878	3.730	
5	4.878	4.650	R^2=0.9982
6	5.811	5.890	
7	6.667	6.410	SE=0.1373
8	7.443	7.420	
9	8.139	8.120	MPE = -0.104144
10	8.758	8.640	
11	9.304	8.850	SD =0.15763
15	10.871		
20	11.861		Y=12.539*(1-exp (-
25	12.282		0.0625*X^-1.2829))
30	12.447		
35	12.508		
40	12.529		
45	12.536		
50	12.539		

Table 1 contd…

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Age (years)	Estimated values	Observed values	Growth model
T_7- *Eucalyptus hybrid*			
1	0.360	0.520	Exponential model
2	0.902	0.850	
3	1.493	1.490	
4	2.077	2.010	
5	2.626	2.650	R^2=0.9933
6	3.123	3.130	
7	3.560	3.510	SE=0.192
8	3.936	3.990	
9	4.255	4.310	MPE =0.04334
10	4.519	4.420	
11	4.736	4.510	SD =0.32964
15	5.248		
20	5.458		Y=15.879*exp (-
25	5.506		11.356/(X+2.573))
30	5.516		
35	5.518		
40	5.518		
45	5.518		
50	5.518		
T_8- *Hardwickia binata*			
1	0.260	0.310	Exponential model
2	0.716	0.730	
3	1.274	1.460	
4	1.893	2.090	
5	2.543	2.590	R^2=0.9991
6	3.204	3.110	
7	3.859	3.550	SE=0.10013
8	4.496	4.780	
9	5.106	5.390	MPE =--1.2767
10	5.682	5.620	
11	6.219	5.910	SD =0.35296
15	7.958		
20	9.280		Y=11.975*exp (-
25	9.938		5.674/(X+1.684))
30	10.227		
35	10.342		
40	10.383		
45	10.397		
50	10.401		

Table 1 contd…

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Age (years)	Estimated values	Observed values	Growth model
T_9-*Ingadulce*			
1	0.767	0.81	Gompertz model
2	1.208	1.23	
3	1.730	1.79	
4	2.297	2.21	
5	2.874	2.79	R^2=0.9968
6	3.430	3.34	
7	3.945	3.86	SE=0.1023
8	4.406	4.29	
9	4.807	4.61	MPE = -0.08557
10	5.150	4.99	
11	5.438	5.19	SD =0.097399
15	6.162		
20	6.512		Y=6.6737*exp (-
25	6.624		2.7339*exp (-0.236))
30	6.658		
35	6.669		
40	6.672		
45	6.673		
50	6.674		
T_{10}- *Pongamia pinnata*			
1	0.160	0.130	Weibull model
2	0.547	0.490	
3	1.085	1.090	
4	1.709	1.820	
5	2.356	2.340	R^2=0.9991
6	2.980	2.890	
7	3.545	3.560	SE=0.0583
8	4.031	4.060	
9	4.429	4.420	MPE = -0.003014
10	4.742	4.770	
11	4.979	4.960	SD =0.052112
15	5.407		
20	5.486		Y=5.5911*(1-exp (-
25	5.491		0.0295*X^1.8292))
30	5.491		
35	5.491		
40	5.491		
45	5.491		
50	5.491		

Table 1 contd...

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Age (years)	Estimated values	Observed values	Growth model
T_{11}- *Syzygium cumini*			
1	0.520	0.580	Exponential model
2	0.789	0.720	
3	1.056	0.980	
4	1.308	1.360	
5	1.542	1.650	R^2=0.9927
6	1.757	1.720	
7	1.953	1.920	SE=0.0656
8	2.131	2.090	
9	2.294	2.330	MPE =0.0000665
10	2.442	2.460	
11	2.578	2.560	SD =0.05874
15	3.020		
20	3.413		Y=5.381*exp (-
25	3.696		10.74/(X+3.595))
30	3.909		
35	4.074		
40	4.206		
45	4.314		
50	4.404		
T_{12}-*Tamarindus indica*			
1	0.285	0.37	Gompertz model
2	0.555	0.49	
3	0.909	0.89	
4	1.309	1.29	
5	1.713	1.78	R^2=0.9976
6	2.090	2.09	
7	2.422	2.37	SE=0.0528
8	2.700	2.7	
9	2.926	2.96	MPE =0.00197
10	3.105	3.13	
11	3.244	3.21	SD =0.047194
15	3.540		
20	3.644		Y=3.3674*exp (-
25	3.667		3.459*exp (-0.3023*X))
30	3.672		
35	3.674		
40	3.674		
45	3.674		
50	3.674		

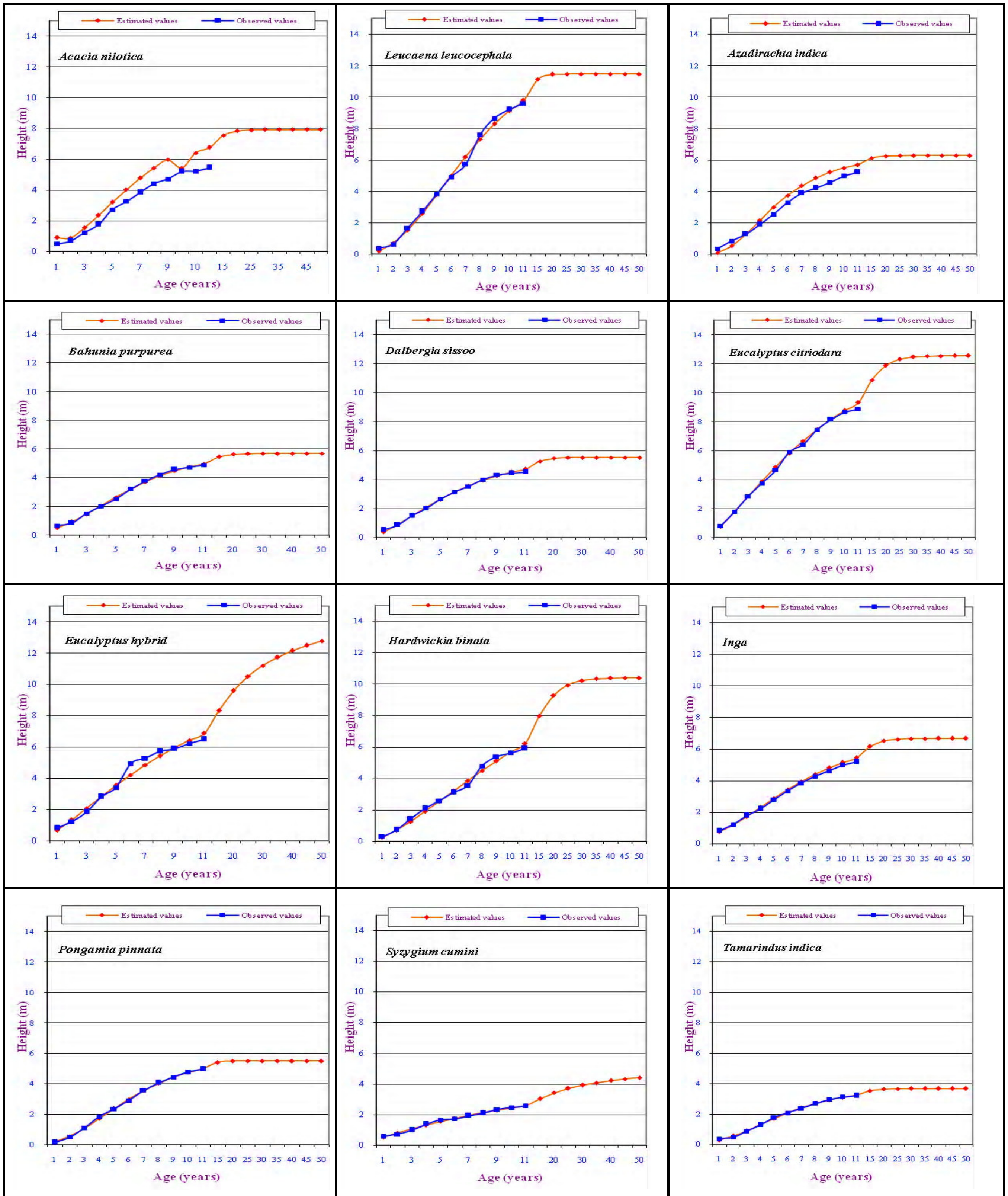

Fig. 1 : Height-age growth curves of different multipurpose tree species under semi-arid regions of north Karnataka

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