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***RESEARCH PAPER***

# Diameter-age growth curve modelling for different multipurpose tree species in dryland of North Karnataka

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**Abstract :** Among 12 multipurpose tree species tested for predicting diameter at breast height (DBH) and age relationship under agroforestry systems of northern dry zone of Karnataka, Gomptertz model showed best fit for 9 species *viz*., *Acacia nilotica,* ($R^2$ = 0.9938), *Bahunia purpurea* ($R^2$ = 0.9950), *Dalbergia sissoo* ($R^2$ = 0.9944), *Eucalyptus citriodara* ($R^2$ = 0.9983), *Eucalyptus hybrid* ($R^2$ = 0.9988), *Hardwickia binata* ($R^2$ = 0.9969), *Inga dulce* ($R^2$ = 0.9931), *Syzygium cumini* ($R^2$ = 0.9976) and *Tamarindus indica* ($R^2$ = 0.9953), where as, Exponential model for 2 species and only one species showed its fitness to Weibull model. Hence, Gompertz model can be best adopted while predicting diameter and age growth of native species grown under dry land situation.

**Key Words :** DBH, Age, Model, Species, Growth

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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 (Curtis, 1967; 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. The general diameter/age relationship is represented by the cumulative growth curve (CGC) which is sigmoidal for biological systems.

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 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 dry land conditions of north Karnataka.

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## MATERIALS AND 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 diameter (cm) of trees was measured using calipers.

Developing diameter growth curves for 12 different 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 |

## RESULTS AND DISCUSSION

Among the different models tried in predicting DBH-Age growth relations of multipurpose trees, Gompertz model found better for *Acacia nilotica,* ($R^2$ = 0.9938), likewise in case of *Bahunia purpurea* ($R^2$ = 0.9950), *Dalbergia sissoo* ($R^2$ = 0.9944), *Eucalyptus citriodara* ($R^2$ = 0.9983), *Eucalyptus hybrid* ($R^2$ = 0.9988), *Hardwickia binata* ($R^2$ = 0.9969), *Inga dulce* ($R^2$ = 0.9931), *Syzygium cumini* ($R^2$ = 0.9976) and

**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**

| $T_1$. *Acacia nilotica* | | | | $T_2$. *Leucaena leucocephala* | | | |
|---|---|---|---|---|---|---|---|
| Age (years) | Estimated values | Observed values | Growth model | Age (years) | Estimated values | Observed values | Growth model |
| 1 | 1.293 | 0.890 | Gompertz model | 1 | 0.314 | 0.810 | Exponential |
| 2 | 1.574 | 1.430 | | 2 | 0.902 | 1.210 | model |
| 3 | 1.884 | 1.890 | | 3 | 1.722 | 1.810 | |
| 4 | 2.219 | 2.350 | $R^2$=0.9938 | 4 | 2.664 | 2.550 | |
| 5 | 2.577 | 2.660 | | 5 | 3.649 | 3.440 | |
| 6 | 2.955 | 3.010 | SE=0.0567 | 6 | 4.627 | 4.490 | $R^2$=0.9958 |
| 7 | 3.347 | 3.440 | | 7 | 5.571 | 5.530 | |
| 8 | 3.750 | 3.800 | MPE =-0.004601 | 8 | 6.467 | 5.990 | SE=0.2121 |
| 9 | 4.161 | 4.200 | | 9 | 7.309 | 6.090 | |
| 10 | 4.574 | 4.610 | SD =0.14957 | 10 | 8.096 | 6.340 | MPE =-0.4726 |
| 11 | 4.988 | 4.990 | | 11 | 8.829 | 6.690 | |
| 15 | 6.579 | | Y=12.331*exp (- | 15 | 11.290 | | SD =0.8567 |
| 20 | 8.283 | | 2.471*exp (- | 20 | 13.550 | | |
| 25 | 9.583 | | 0.0193*X)) | 25 | 15.206 | | Y=25.3495*exp |
| 30 | 10.511 | | | 30 | 16.464 | | (-13.881/ |
| 35 | 11.144 | | | 35 | 17.448 | | (2.1612+X)) |
| 40 | 11.565 | | | 40 | 18.238 | | |
| 45 | 11.840 | | | 45 | 18.886 | | |
| 50 | 12.018 | | | 50 | 19.427 | | |

*Table 1 contd...*

*Contd… Table 1*

| Age (years) | Estimated values | Observed values | Growth model | Age (years) | Estimated values | Observed values | Growth model |
|---|---|---|---|---|---|---|---|
| $T_3$- *Azadirachta indica* | | | | $T_5$- *Dalbergia sissoo* | | | |
| 1 | 0.361 | 0.330 | Weibull model | 1 | 0.622 | 0.910 | Gompertz model |
| 2 | 0.983 | 0.780 | | 2 | 0.966 | 1.260 | |
| 3 | 1.728 | 1.560 | | 3 | 1.508 | 1.710 | |
| 4 | 2.529 | 2.410 | $R^2$=0.9983 | 4 | 2.129 | 2.380 | |
| 5 | 3.342 | 3.290 | | 5 | 2.780 | 2.810 | $R^2$=0.9944 |
| 6 | 4.138 | 4.110 | SE=0.11055 | 6 | 3.418 | 3.530 | |
| 7 | 4.894 | 4.760 | | 7 | 4.011 | 4.190 | SE=0.04591 |
| 8 | 5.596 | 5.550 | MPE =-0.15801 | 8 | 4.540 | 4.620 | |
| 9 | 6.237 | 6.110 | | 9 | 4.997 | 5.090 | MPE |
| 10 | 6.812 | 6.420 | SD =0.14015 | 10 | 5.382 | 5.460 | =0.15335699 |
| 11 | 7.320 | 6.880 | | 11 | 5.700 | 5.780 | |
| 15 | 8.752 | | | 15 | 6.466 | | SD =0.093458 |
| 20 | 9.568 | | | 20 | 6.805 | | |
| 25 | 9.847 | | Y=9.954*(1-exp | 25 | 6.902 | | |
| 30 | 9.928 | | (-0.0369* | 30 | 6.929 | | Y=7.94*exp (- |
| 35 | 9.948 | | X^1.4948)) | 35 | 6.937 | | 3.29*exp (- |
| 40 | 9.953 | | | 40 | 6.939 | | 0.256*X)) |
| 45 | 9.954 | | | 45 | 6.940 | | |
| 50 | 9.954 | | | 50 | 6.940 | | |
| $T_4$- *Bahunia purpurea* | | | | $T_6$- *Eucalyptus citriodara* | | | |
| 1 | 0.386 | 0.510 | Gompertz model | 1 | 0.813 | 0.970 | Gompertz model |
| 2 | 0.935 | 0.880 | | 2 | 1.604 | 1.760 | |
| 3 | 1.741 | 1.550 | | 3 | 2.625 | 2.530 | |
| 4 | 2.697 | 2.490 | | 4 | 3.753 | 3.580 | |
| 5 | 3.669 | 3.560 | $R^2$=0.9950 | 5 | 4.864 | 4.810 | $R^2$=0.9983 |
| 6 | 4.556 | 4.410 | | 6 | 5.871 | 5.890 | |
| 7 | 5.305 | 5.220 | SE=0.05654 | 7 | 6.729 | 6.880 | SE=0.03955 |
| 8 | 5.905 | 5.790 | | 8 | 7.429 | 7.340 | |
| 9 | 6.366 | 6.310 | MPE =-0.09723 | 9 | 7.983 | 7.990 | MPE =-0.00771 |
| 10 | 6.712 | 6.620 | | 10 | 8.409 | 8.310 | |
| 11 | 6.967 | 6.830 | SD =0.088346 | 11 | 8.733 | 8.670 | SD =0.11633 |
| 15 | 7.447 | | | 15 | 9.387 | | |
| 20 | 7.582 | | | 20 | 9.597 | | |
| 25 | 7.605 | | Y=7.61*exp (- | 25 | 9.639 | | |
| 30 | 7.609 | | 4.24*exp (- | 30 | 9.648 | | Y=9.65*exp (- |
| 35 | 7.610 | | 0.352*X)) | 35 | 9.650 | | 3.41*exp (- |
| 40 | 7.610 | | | 40 | 9.650 | | 0.321*X)) |
| 45 | 7.610 | | | 45 | 9.650 | | |
| 50 | 7.610 | | | 50 | 9.650 | | |

*Table 1 contd…*

*Contd… Table 1*

| Age (years) | Estimated values | Observed values | Growth model | Age (years) | Estimated values | Observed values | Growth model |
|---|---|---|---|---|---|---|---|
| $T_7$- *Eucalyptus hybrid* | | | | $T_9$-*Inga dulce* | | | |
| 1 | 0.755 | 0.910 | Gompertz model | 1 | 0.492 | 0.810 | Gompertz model |
| 2 | 1.490 | 1.610 | | 2 | 1.074 | 1.260 | |
| 3 | 2.443 | 2.360 | | 3 | 1.868 | 1.910 | |
| 4 | 3.501 | 3.410 | | 4 | 2.768 | 2.550 | |
| 5 | 4.550 | 4.630 | $R^2$=0.9988 | 5 | 3.659 | 3.620 | $R^2$=0.9931 |
| 6 | 5.507 | 5.610 | | 6 | 4.461 | 4.510 | |
| 7 | 6.328 | 6.390 | SE=0.03191 | 7 | 5.134 | 5.230 | SE=0.29147 |
| 8 | 7.001 | 6.990 | | 8 | 5.672 | 5.710 | |
| 9 | 7.536 | 7.210 | MPE =-0.05821 | 9 | 6.089 | 6.020 | MPE =0.02059 |
| 10 | 7.952 | 7.580 | | 10 | 6.402 | 6.310 | |
| 11 | 8.268 | 7.990 | SD =0.18594 | 11 | 6.635 | 6.550 | SD =0.14686 |
| 15 | 8.914 | | | 15 | 7.081 | | |
| 20 | 9.125 | | | 20 | 7.210 | | |
| 25 | 9.169 | | | 25 | 7.234 | | |
| 30 | 9.178 | | Y=9.18*exp (- | 30 | 7.238 | | Y=7.239*exp (- |
| 35 | 9.180 | | 3.43*exp (- | 35 | 7.239 | | 3.789*exp (- |
| 40 | 9.180 | | 0.3173*X)) | 40 | 7.239 | | 0.3429*X)) |
| 45 | 9.180 | | | 45 | 7.239 | | |
| 50 | 9.180 | | | 50 | 7.239 | | |
| $T_8$- *Hardwickia binata* | | | | $T_{10}$- *Pongamia pinnata* | | | |
| 1 | 0.676 | 0.950 | Gompertz model | 1 | 0.737 | 0.810 | Exponential model |
| 2 | 1.277 | 1.360 | | 2 | 1.321 | 1.370 | |
| 3 | 2.043 | 2.120 | | 3 | 1.958 | 1.880 | |
| 4 | 2.892 | 2.910 | | 4 | 2.600 | 2.560 | |
| 5 | 3.739 | 3.780 | $R^2$=0.9969 | 5 | 3.221 | 3.310 | $R^2$=0.9987 |
| 6 | 4.521 | 4.610 | | 6 | 3.807 | 3.910 | |
| 7 | 5.202 | 5.290 | SE=0.1366 | 7 | 4.355 | 4.490 | SE=0.7327 |
| 8 | 5.771 | 5.820 | | 8 | 4.862 | 5.010 | |
| 9 | 6.231 | 6.310 | MPE =0.099634 | 9 | 5.331 | 5.540 | MPE =-0.56951 |
| 10 | 6.595 | 6.780 | | 10 | 5.764 | 5.880 | |
| 11 | 6.877 | 6.990 | SD =0.07222 | 11 | 6.163 | 6.010 | SD =0.10793 |
| 15 | 7.474 | | | 15 | 7.485 | | |
| 20 | 7.684 | | | 20 | 8.683 | | |
| 25 | 7.731 | | | 25 | 9.555 | | |
| 30 | 7.741 | | Y=7.744*exp (- | 30 | 10.216 | | Y=14.884*exp (- |
| 35 | 7.743 | | 3.299*exp (- | 35 | 10.732 | | 12.477/(3.1516+X)) |
| 40 | 7.744 | | 0.3022*X)) | 40 | 11.147 | | |
| 45 | 7.744 | | | 45 | 11.486 | | |
| 50 | 7.744 | | | 50 | 11.770 | | |

*Table 1 contd…*

*Contd... Table 1*

| Age (years) | Estimated values | Observed values | Growth model | Age (years) | Estimated values | Observed values | Growth model |
|---|---|---|---|---|---|---|---|
| $T_{11}$- ***Syzygium cumini*** | | | | $T_{12}$-*Tamarindus indica* | | | |
| 1 | 0.736 | 0.830 | | 1 | 0.893 | 0.760 | Gompertz model |
| 2 | 1.111 | 1.210 | Gompertz model | 2 | 1.262 | 1.560 | |
| 3 | 1.546 | 1.620 | | 3 | 1.683 | 2.280 | |
| 4 | 2.014 | 2.110 | | 4 | 2.137 | 2.970 | |
| 5 | 2.491 | 2.560 | $R^2$=0.9976 | 5 | 2.606 | 3.310 | $R^2$=0.9953 |
| 6 | 2.952 | 2.990 | | 6 | 3.073 | 3.760 | |
| 7 | 3.384 | 3.420 | SE=0.07545 | 7 | 3.524 | 4.010 | SE=0.1082 |
| 8 | 3.774 | 3.810 | | 8 | 3.949 | 4.420 | |
| 9 | 4.120 | 4.280 | MPE =0.056182 | 9 | 4.341 | 4.790 | MPE =0.46213 |
| 10 | 4.419 | 4.460 | | 10 | 4.695 | 5.010 | |
| 11 | 4.675 | 4.550 | SD =0.07098 | 11 | 5.012 | 5.390 | |
| 15 | 5.342 | | | 15 | 5.927 | | SD=0.25991 |
| 20 | 5.688 | | | 20 | 6.500 | | |
| 25 | 5.807 | | | 25 | 6.741 | | |
| 30 | 5.847 | | Y=5.8668*exp (- | 30 | 6.840 | | Y=6.904*exp (- |
| 35 | 5.860 | | 2.591*exp | 35 | 6.879 | | 2.46*exp (- |
| 40 | 5.865 | | (0.2213*X)) | 40 | 6.894 | | 0.185*X)) |
| 45 | 5.866 | | | 45 | 6.900 | | |
| 50 | 5.867 | | | 50 | 6.903 | | |

*Tamarindus indica* ($R^2$ = 0.9953) Gompertz was found to fit better. Where as, Exponential model fit well for *Leucana leucocephala* ($R^2$ = 0.9958) and *Pongamia pinnata* ($R^2$ = 0.9987), followed by Weibull model for *Azadirachta indica* ($R^2$ = 0.9983) (Table 1 and Fig. 1).

Among five growth models tested in diameter and age relationship study, Korf and Richards model showed least fit in almost every tree species. Among other three models Gompertz model showed best fit with highest $R^2$ and lest standard error. Among twelve multipurpose tree species, Gomptertz model showed best fit for 9 species among which seven species were native to semiarid conditions. Gompertz model showed faster early growth but slower approach to asymptote with a longer linear period about inflection point (Thornley and France, 2007) and reported to be more accurate than any other models of forest growth (Zhang, 1997). Arid conditions of the experimental site might also impart such slow approach to the asymptote. Weibull model better fitted for 2 species with highest $R^2$ and lesser standard error and parameters with asymptote t-values. Exponential model showed best fit for two species *i.e*. *Leucana leucocephala* which is introduced fast growing species and *Pongamia pinnata* a biofuel yielding tree species. 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.. But overall performance of models was better in which all models were showed $R^2$ between 0.98 and 0.99 except Korf and Weibull model. Mean prediction error, standard deviation and $R^2$ were adopted as criteria for comparing model prediction performance of growth functions. The apparent reason for high $R^2$ values associated with linear models is that the data set usually belongs to the second phase of tree growth and which is linear in nature (Srivastava and Ajit, 2002). In this, Gompertz function showed superiority over other models for 9 species in DBH – age relationship.

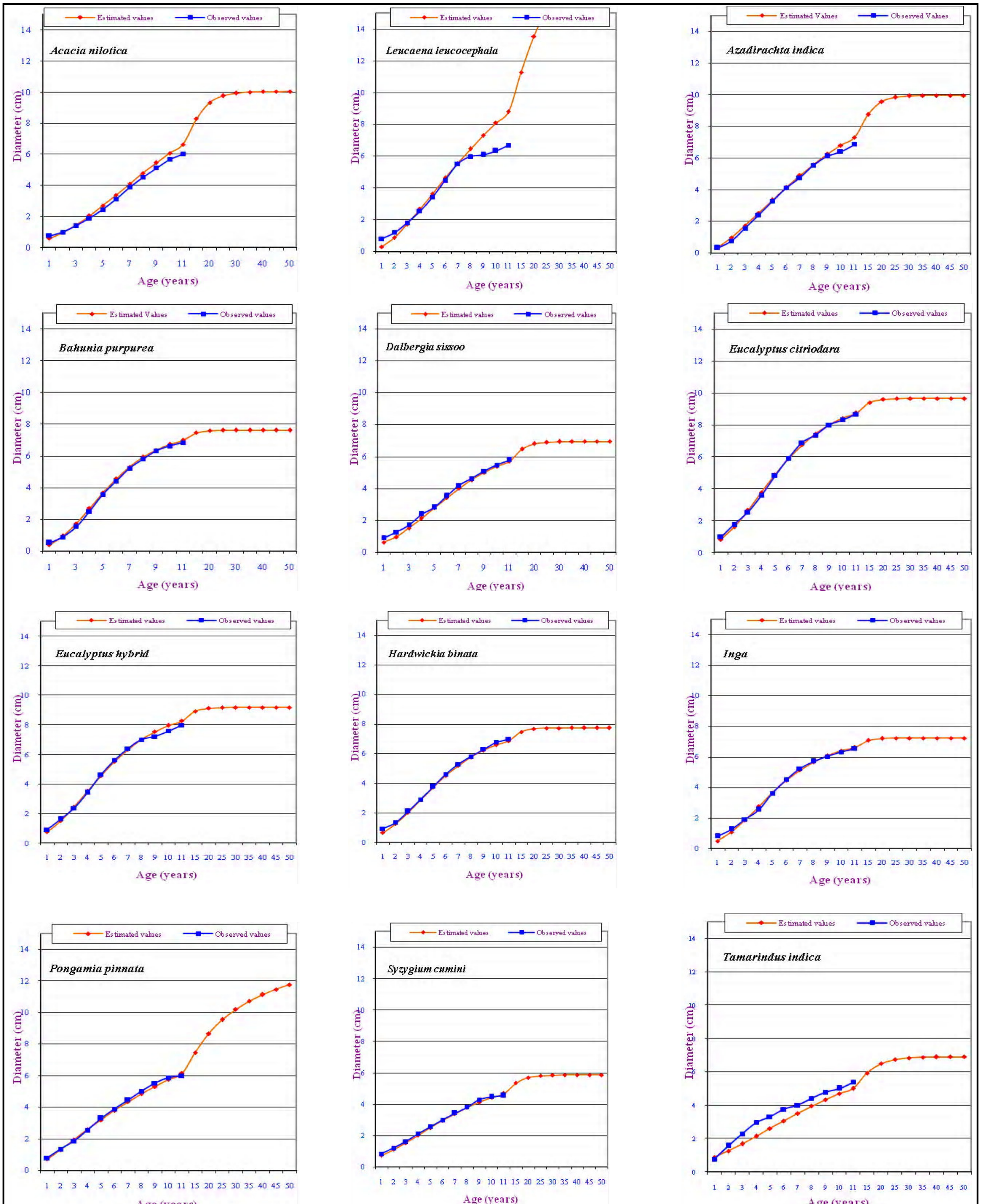


**Fig. 1 : Diameter -age growth curves of different multipurpose tree species under semi-arid regions of north Karnataka**

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