THEME:
NATURAL FOREST MANAGEMENT / BIODIVERSITY

Title of the technology

Growth and yield models for some forest plantations in Rajasthan and Gujarat for their sustainable management

A. Nature of technology

Growth & yield models for plantations (knowledge generation useful for management of plantation)

B. Process in brief

The key to successful forest/timber management is a proper understanding of growth processes, and one of the objectives of modelling forest development is to provide the tools that enable foresters to compare alternative silvicultural treatments. Information about the growth and yield of many plantation species is scarce and for this reason growth models have become very important. No models are yet available for estimating productivity and projecting basal area and mortality for many species which is crucial for evaluating different silvicultural treatment options.

Growth modelling is an essential prerequisite for evaluating the consequences of a particular management action on the future development of a forest ecosystem. Development of sound management practices is one of the major priorities of the forestry sector. Accurate predictions of stand growth and yield are needed for determining sustainable harvests. Technologically advanced growth and yield prediction tools can help foresters make more informed management decisions.

Thirty sample plots of *D. sissoo*, 35 of *E. camaldulensis* and 22 of *T. undulata* were laid out in the IGNP area of Rajasthan and 34 sample plots of *E.* hybrid, 22 of *A. nilotica* and six of neem were established at various locations in Gujarat, covering the available age groups and stand densities, using stratified multistage sampling. The plots, covering approximately 0.1 ha, are representative of the growing conditions in the area. Annual measurements were taken continuously for 5 years in *D. sissoo*, *E. camaldulensis*, *E.* hybrid, *A. nilotica* and neem plots and for 3 years in *T. undulata* plots. Two phase sampling was adopted for enumeration of trees in each plot. First the diameters of all the trees within the plots were measured and then a sub-sample of diameter-height pairs was taken which was subsequently used to determine the height and dbh regression. The height of the other trees in the sample plots was estimated using this regression equation. The same sampling procedure was adopted for volume estimation of the trees in the plot. Trees, covering different diameter classes in the plots, were felled from the surround of the plots and measured for D, H and timber and wood volumes (overbark and under bark). Allometric relationship between volumes and D^2H were derived for volume predictions. The volume equation developed was applied on the trees within the plots to estimate wood volume per hectare. The trees of desired diameter class were felled from the surrounding of the plot to keep the sample plots undisturbed. The plot data included a record of the age (A), the dominant stand height (H), the quadratic mean diameter (D_g), the stems/ha (N), the basal area/ha (BA) etc. A total of 71 sample trees of *D. sissoo*, 91 of *E. camaldulensis*, 75 of *T. undulata*, 114 of *E.* hybrid, 56 of *A. nilotica* and 31 of neem were felled for constructing volume equations.

No thinning was done in the stands and the decline in the stem numbers per hectare was caused by the natural mortality or self-thinning. The other probable reasons of mortality were recurrent droughts, water-logging and pathogenic problems at some locations, etc.

The models tested and developed were qualitatively and quantitatively evaluated based on formal statistical tests and were validated on independent dataset using criterion based procedures.

Total wood volume equations

E. camaldulensis

$$V = 0.000169*D^{2.41298}$$

$$V = -0.00226 + 0.0000333\ D^2H$$

D. sissoo

$$V = 0.01328 – 0.00538\ D + 0.000760\ D^2$$

$$V = -0.0023 + 0.0000364\ D^2H$$

T. undulata

$$V = 0.000088\ D^{2.381398}$$

$$V = 0.000066\ D^{2.100121}H^{0.553696}$$

A. indica

$$V = 0.07033 - 0.01387*D + 0.0009853*D^2$$

$$V= -0.00989 + 0.0000184*DH + 0.0000438*D^2H$$

E. hybrid

$$V = 0.000076*D^{2.761477}$$

$$V = 0.000014*D^{2.141947}H^{1.168588}$$

A. nilotica

$$V = 0.000071*D^{2.735778}$$

$$V = 0.000018*D^{2.363677}H^{0.938962}$$

Where, V is the total wood volumes (in m^3) over-bark, D is the dbh in cm and H is the total tree height in m.

The volume yield vs. stand age curves for *D. sissoo* plantations in IGNP area for different site classes are shown in Fig. 1 while volume vs. dbh curve for *E.* hybrid in Gujarat in presented in Fig. 2.

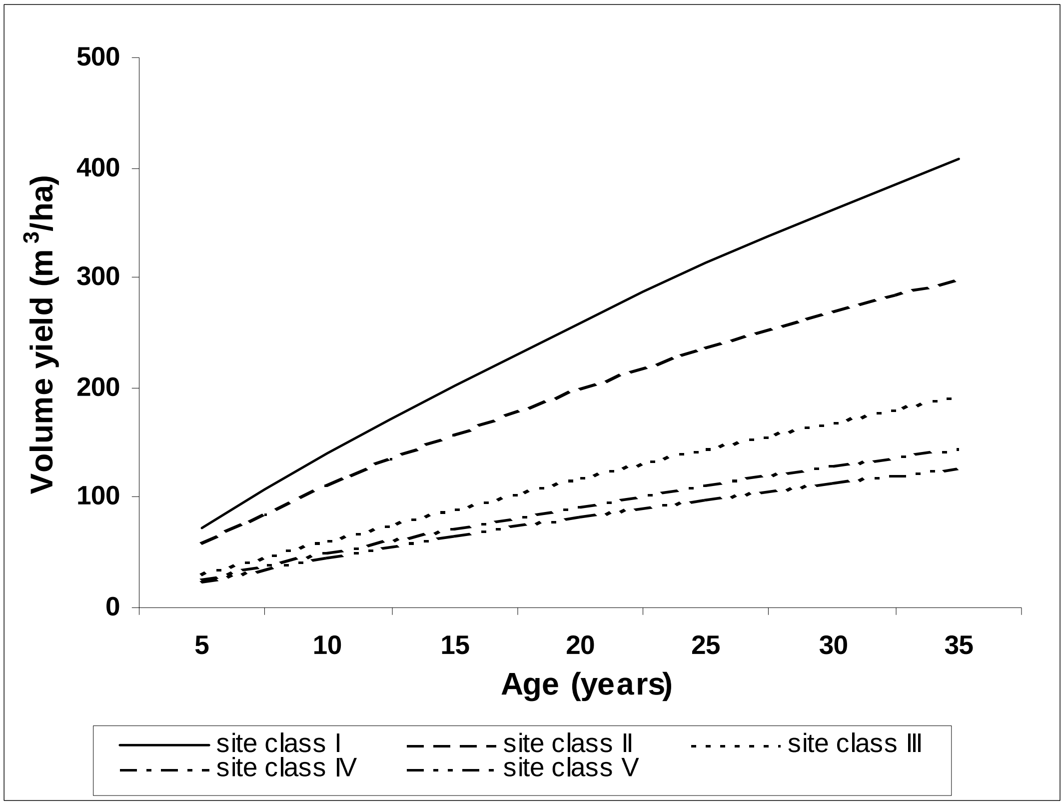


Fig.1. Volume yield vs. stand age curves for *D. sissoo* plantations for different site classes.

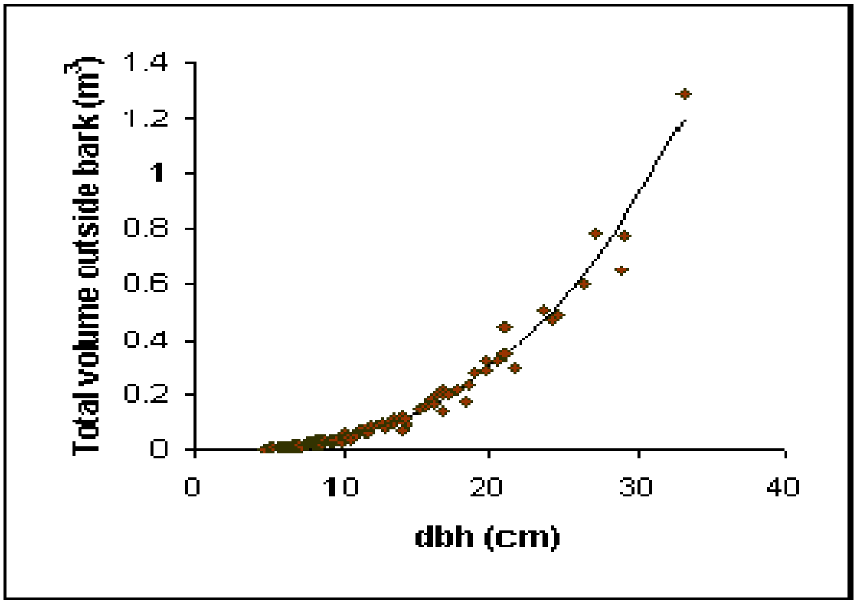


Fig. 2. Volume vs. dbh curve for *E.* hybrid

Site index equations

_E. camaldulensi_s

$$H_2 = 3.9569 H_1^{0.7584}\left(1 - e^{-0.0278 t_2}\right)^d$$

where, $d=\ln[H_1/(3.9569\ H_1^{0.7584})]/\ln[1-\exp(-0.0278 t_1)]$

D. sissoo

$$H_2 = H_1\left[\frac{1-\exp\left\{-0.00004\left(\frac{H_1}{t_1}\right)^{-7.4008} t_1^{1.6645} t_2\right\}}{1-\exp\left\{-0.00004\left(\frac{H_1}{t_1}\right)^{-7.4008} t_1^{1.6645} t_1\right\}}\right]^{0.2478}$$

T. undulata

$$H_2 = 14.9078 H_1^{-0.0539}\left(1 - e^{-0.0182 t_2}\right)^d + \varepsilon$$

where, $d = \dfrac{\ln\left[\dfrac{H_1}{14.9078\ H^{-0.0539}}\right]}{\ln\left[1-\exp\left(-0.0182\ * t_1\right)\right]}$

_E._ hybrid

$$H_2 = 130.2464\left(H_1/130.2464\right)^{\exp(Z)}$$

with, $Z = 0.1098/(0.5129-1)A_2^{(b_3-1)} - 0.1098/(0.5129-1)A_1^{(0.5129-1)}$

A. nilotica

$$H_2 = 58.4434\left(H_1/58.4434\right)^{\exp(Z)}$$

with, $Z = 0.0635/(0.3073-1)A_2^{(b_3-1)} - 0.0635/(0.3073-1)A_1^{(0.3073-1)}$

The height growth curves for *D. sissoo* plantations in IGNP area for different site classes are presented in Fig. 3 while site index curves for *T. undulata*, *E.* hybrid and *A. nilotica* are shown in Fig. 4.

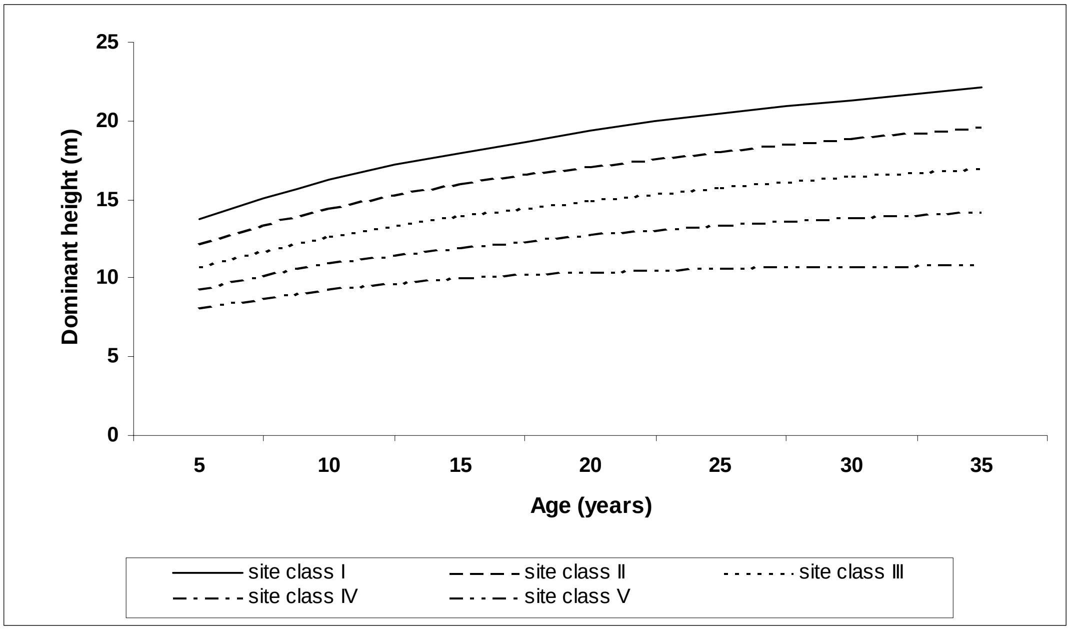
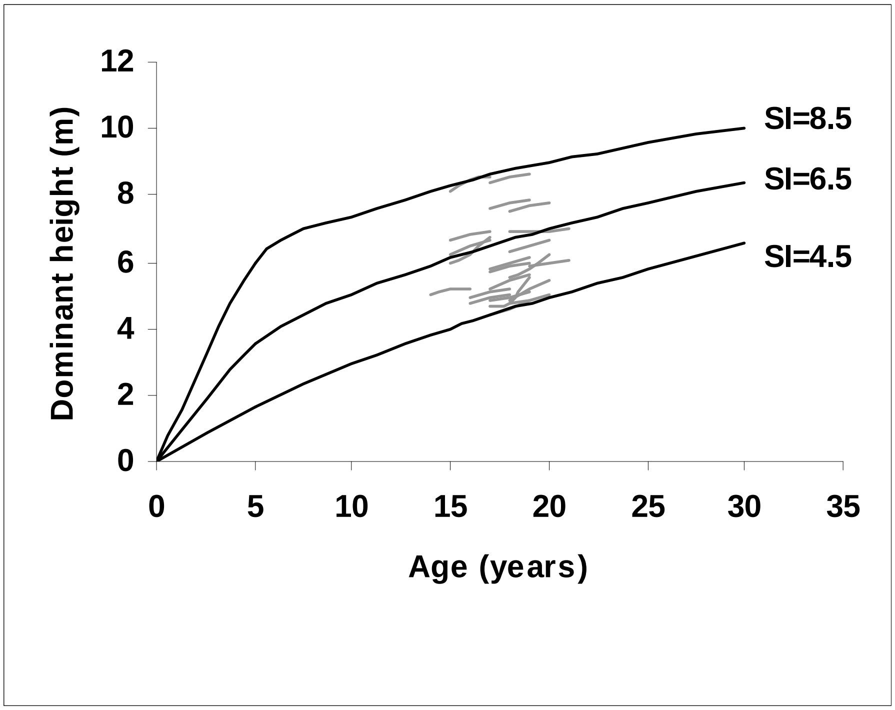
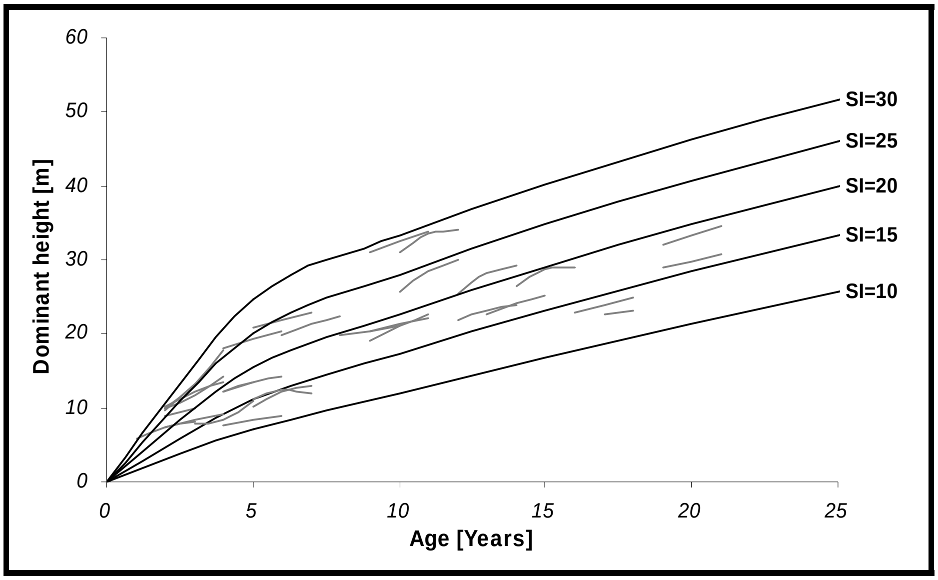


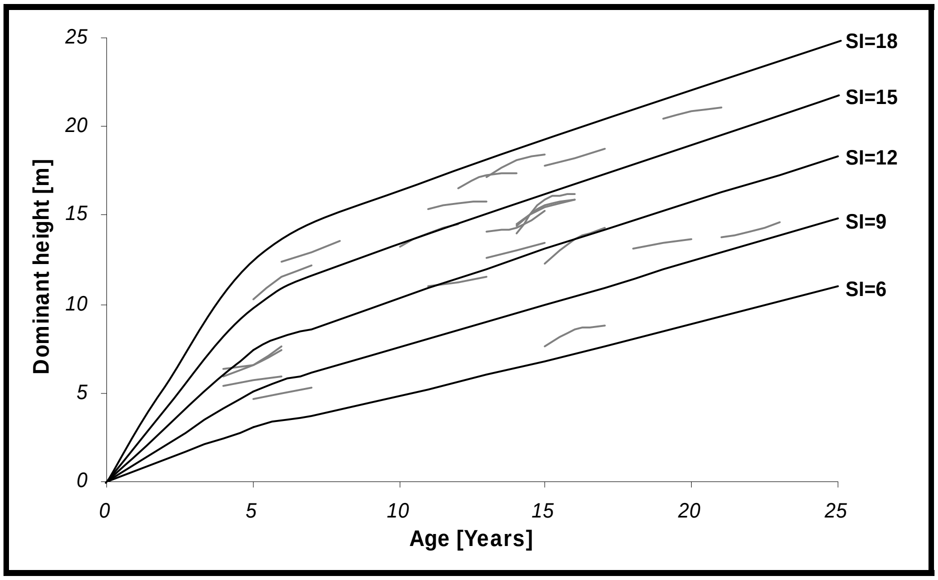
Fig. 3. Height growth curves for *D. sissoo* plantations for different site classes.



(a)



(b)



(c)

Fig. 4. Site index curves generated for (a) *Tecomella undulata*, (b) *E.* hybrid and (c) *A. nilotica*

Potential (limiting stand) density

E. camaldulensis

$$N_{G\max} = 35835.69 D_{G\max}^{-1.1905}$$

D. sissoo

$$N_{G\max} = 68761.87 D_{G\max}^{-1.5109}$$

T. undulata

$$N_{G\max} = 57629.65 D_{G\max}^{-1.46966}$$

A. indica

$$N_{G\max} = 54905.39 D_{G\max}^{-1.48687}$$

***E*. hybrid**

$$N_{G\max} = 29443.7 D_{G\max}^{-1.16145}$$

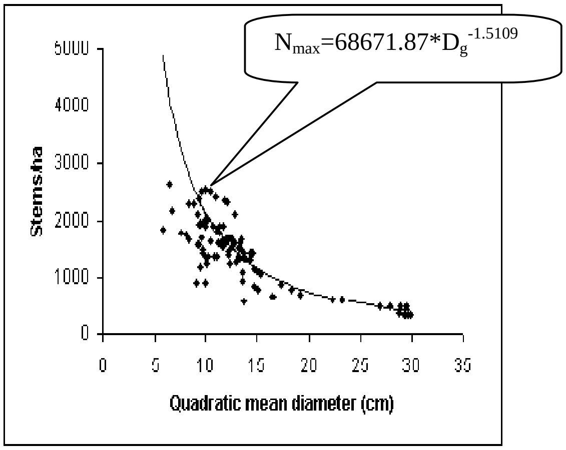
A. nilotica

$$N_{G\max} = 23972.26 D_{G\max}^{-1.31384}$$

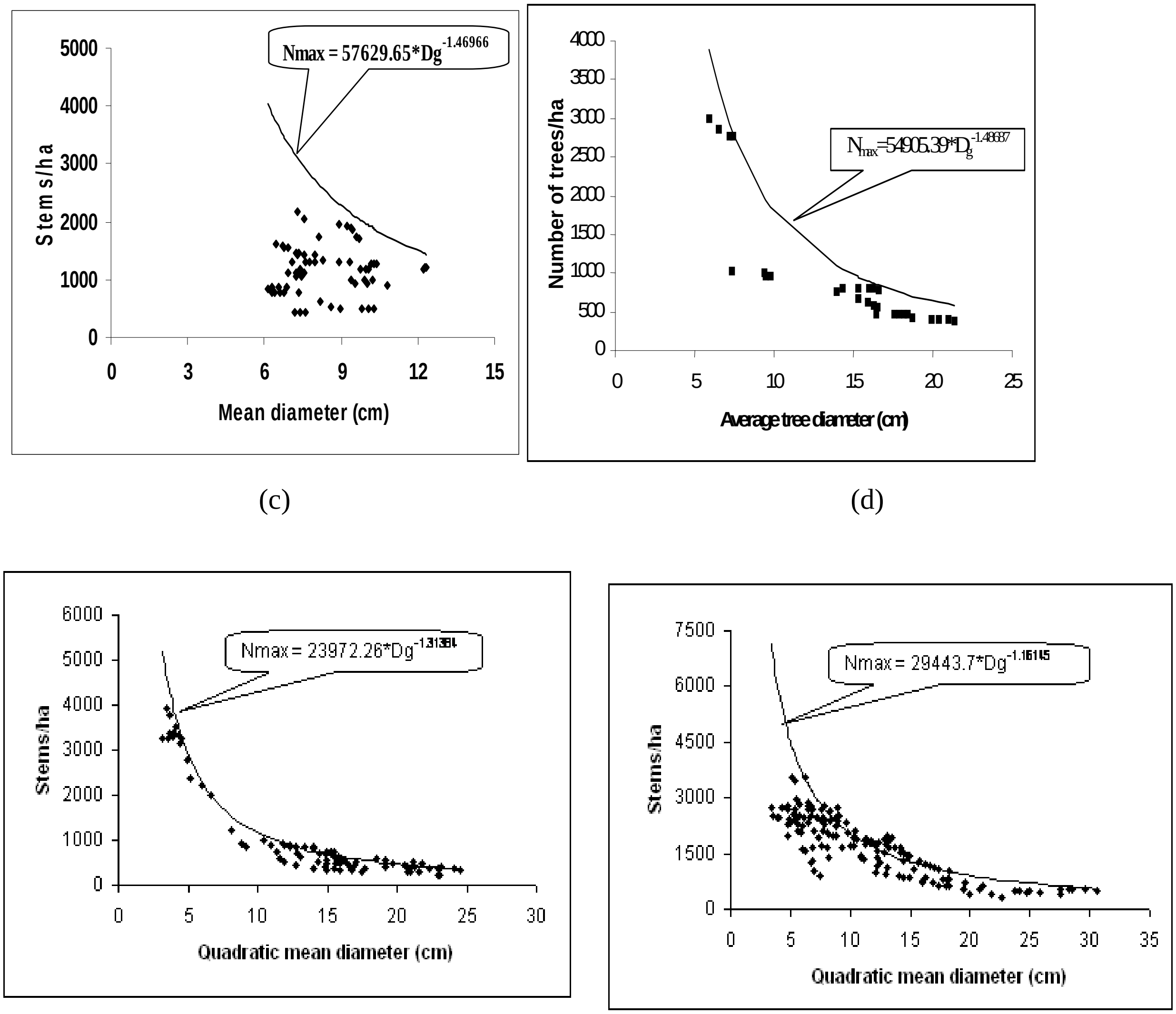
The relationship between the quadratic mean diameter and the number of living trees per unit area along with the limiting line is shown in Fig. 5. The solid line in the figure represents the potential density in the plots, i.e., the maximum stems ha^{-1} the plots can have with respect to the quadratic mean diameter at maximum basal area.

N_{max}=35835.69*$D_g^{-1.1905}$

(a)



(b)



(c) (d)

(e) (f)

Fig. 5. Relationship between stems/ha and quadratic mean diameter; (a) for *E. camaldulensis*, (b) for *D. sissoo*, (c) for *T. undulate*, (d) for neem, (e) for *A. nilotica* and (f) for *E.* hybrid. The solid line is limiting line. The equation is derived from equation 9.

Stem number development

The equations for estimating the rate of change in the number of stems per ha in the stands are:

<u>E. camaldulensis</u>

$$N_2 = \left[N_1^{0.5027} + \left(-3.0526 + \frac{21.3766}{SI} \right) \left(\left[\frac{A_2}{10} \right]^{2.4940} - \left[\frac{A_1}{10} \right]^{2.4940} \right) \right]^{\frac{1}{0.5027}}$$

D. sissoo

$$N_2 = \left[N_1^{0.14148} + 0.00686\,(A_1^{1.27431} - A_2^{1.27431})\right]^{\frac{1}{0.14148}}$$

A. indica

$$N_2 = \left[N_1^{0.000033} + \left(-0.000012 + \frac{0.000046}{SI}\right)\left(\left[\frac{A_2}{10}\right]^{0.956197} - \left[\frac{A_1}{10}\right]^{0.956197}\right)\right]^{\frac{1}{0.000033}}$$

Basal area prediction model

E. camaldulensis

$$\ln(BA_2) = \ln(BA_1) - 3.0211*\left(\frac{1}{A_2} - \frac{1}{A_1}\right) + 0.5055*(\ln N_2 - \ln N_1) + 0.66626*(\ln H_2 - \ln H_1)$$

D. sissoo

$$\ln(BA_2) = \ln(BA_1) + 2.3593*\left(\frac{1}{A_2} - \frac{1}{A_1}\right) + 0.7704*(\ln N_2 - \ln N_1) + 0.8095*(\ln H_2 - \ln H_1) - 2.1481*\left(\frac{\ln H_2}{A_2} - \frac{\ln H_1}{A_1}\right)$$

T. undulata

$$BA_2 = BA_1 * N_2^{1-0.19396 * H_2^{0.56317}} * N_1^{0.19396 * H_1^{0.56317} - 1} * \left(\frac{H_2}{H_1}\right)^{3.94394}$$

***E.* hybrid**

$$\ln(BA_2) = \ln(BA_1) - 0.9861*\left(\frac{1}{A_2} - \frac{1}{A_1}\right) + 0.4344*(\ln N_2 - \ln N_1) + 1.062*(\ln H_2 - \ln H_1) + 0.2639*\left(\frac{\ln H_2}{A_2} - \frac{\ln H_1}{A_1}\right)$$

A. nilotica

$$\ln(BA_2) = \ln(BA_1) - 1.6416*\left(\frac{1}{A_2} - \frac{1}{A_1}\right) + 0.5636*(\ln N_2 - \ln N_1) + 0.8758*(\ln H_2 - \ln H_1)$$

where,

BA_1 and BA_2 = basal area (m^2) at age A_1 and A_2
H_1 and H_2 = top height at age A_1 and A_2
N_1 and N_2 = Number of stems at age A_1 and A_2

C. Beneficiaries of the technology

1. *Prominent beneficiaries/ user groups*
   State Forest Departments, Forest Development Corporations, Non-Government Organizations, Plantation Companies
2. *No. of clients to whom technology has been transferred/ sold*
   SFD, Rajasthan; SFD, Gujarat; SFD, Haryana; Tree Analysis and Research Unit (TARU) (a NGO, based at Gandhinagar, Gujarat)
3. *Potential for further dissemination*

The models developed may be used by the SFDs, NGOs, Forest Corporations, tree growers and other user agencies involved in raising plantations of the species studied.

D. Economic significance

1. *Potential to address Livelihood issues and generate additional income N.A.*
2. *Productivity enhancement and economic benefits over replaced technology*

Volume equations play a crucial role in forest management. Accurate estimates of tree volume are fundamental for forest ecosystem modelling and regional carbon accounting. Volume equations are critical starting points if forest management is to be successful and efficient. Allometric equations for predicting wood volume play a critical and obvious role in the management of any silvicultural system, and their absence would represent an impediment to developing and implementing management plans geared towards the harvest and utilization of wood products.

The site index equations may be used for assessing productive capacity of site and to select sites suitable for a particular species. These are also useful in estimating site index at base age given height at some other age as well as estimating height at some desired age given site index.

The generalised diameter-height equations can be applied on the plantations available on different sites with varying stocking. These equations are useful tools for forest inventory purposes and are used as important element of many size class models for simulating the development of silvicultural alternatives over time. Sometimes, these are also used to generate individual tree height increment data.

Populations of trees growing at high densities are subject to density-dependent mortality or self-thinning. Estimating the potential density of forest stands, in terms of the surviving trees per ha, is a central element of growth modelling. It is also one of the most difficult problems to solve, mainly because suitable data from untreated, densely stocked stands are rarely found. The limiting line for the potential density describes the relationship between the average tree size and the number of surviving trees per unit area which is helpful in generating information about the maximum number of trees ha^{-1} to be kept in the stands given the mean diameter of the trees in the stands.

The stand basal area is an important density measure, which simultaneously takes into account the average tree size and the number of trees per unit area. The basal area prediction models can be used to analyse the relationship between stand density and tree growth. In combination with the stand density model, the basal area projection models may also be used to define the type and weight of thinnings in the stands. Thus these models are very crucial in evaluating silvicultural treatment options.

Provided the conditions under which these models are applied are the same as those under which the basic data have been collected, such models provide robust tools for prediction of future yield. They can also be used for the evaluation of stand structure and stand productivity in a particular field condition and in general for decision support in forest management and planning. Management oriented empirical growth and yield models are very much relevant in transferring of summary information on forest growth to the forest managers.

3. *Impact* of the technology

The information generated has been used by the SFD, Rajasthan in volume/yield estimation in the plantations in the IGNP area. Similarly, officials of SFD, Gujarat and TARU have also used the volume equations developed in estimating yield. Volume equations are very useful for forest ecosystem modelling and regional carbon accounting.

The site index and limiting density model developed for *E. camaldulensis* has been used by Dr. Denis Alder, Consultant in Forest Biometrics in 'Analysis of the forest inventory for the Laos Industrial Tree Plantation Project' with due acknowledgement of our advice. The model and curves were found to be reasonably representative of the Lao inventory plots too. The details may be seen at http://www.bio-met.co.uk/laos

E. Developed by

V.P. Tewari, Arid Forest Research Institute, Jodhpur.
(Current Address: Institute of Wood Science and Technology, Bangalore).