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Construction and validation of models for timber volume of poplar (*Populus deltoides*) planted in agroforestry in Haryana*

R H RIZVI[1], DIWAKAR KHARE[2] and A K HANDA[3]

National Research Centre for Agroforestry, Jhansi, Uttar Pradesh 284 003

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Poplar (*Populus deltoides* Bartr. ex Marsh.) in India is being raised on an increasing scale as an agroforestry crop by the farmers on their field bunds, agricultural fields, vacant lands, etc. for their domestic needs and for sale. Poplars have been grown on farmlands in single rows along field boundaries, along paths and as blocks. Large-scale planting of poplars by farmers was started since 1979 when Western India Match Company actively participated in the extension programme and found it very excellent for matchwood.

Poplar is found to be the ideal tree both for the farmers and foresters. Their fast growing and deciduous nature, multipurpose use and compatibility with agricultural crops have made them all the more important for agroforestry plantations in Uttar Pradesh, Haryana and Punjab since 1980 (Chaturvedi 1982). Mathur and Sharma (1983) concluded that raising of poplar at 8 years rotation with agriculture on farmland is profitable. The benefit : cost ratio was 3.22 with 12% interest. Chandra (1986) also gave an excellent account of the economics involved in establishing poplar agroforestry. The discounted benefits at 12% over 8 years were Rs 77 336 against the discounted costs of Rs 41 503.

Farmers, foresters and timber merchants are always interested in estimating the timber volume/yield of the standing trees without harvesting them. Availability of statistically tested/proven models would certainly help them in estimating the timber volume of a standing tree. So it is imperative to construct statistically tested models on the basis of tree parameters. Although some researchers have developed models/equations for timber volume of *P. deltoides* (Pandey *et al*. 1998, Singh and Upadhyay 2001, Dhanda and Verma 2001), but they are meant for other states or regions. The validation of a model is essential for examining the predictive ability of the model (Goulding 1979, Reynolds *et al*. 1988). In the present study, an attempt has been made to develop statistically tested and validated non-linear models for predicting timber volume (over bark) of *P. deltoides* for Haryana region.

Poplar-based agroforestry plantations were selected from Karnal, Hisar and Yamunanagar districts of Haryana in northern India in 2005. Tree density of these plantations was 500, 400 and 200 trees/ha and sampled trees includes a total 60 poplar trees of ages 6, 7 and 8 years. Data were recorded on tree height (H), bole height, diameter at breast height (D). Diameter square × height (D^2H) was also computed, which is an important variable in estimation of biomass/volume of a tree. For computation of timber volume, stem up to the point where diameter was more than 10 cm was considered. The timber volume was calculated by cutting stem into logs, measuring diameter in middle of logs and applying Hubers formula for calculating volume of each log. Data were randomly divided into 2 data sets consisting of 40 and 20 trees, former set was used for model construction and latter for model validation. Five non-linear functions widely used in forestry were chosen after literature review (Table 1). These functions were fitted using both D and D^2H as explanatory variables separately for volume (over bark). Non-

Table 1 Non-linear functions used for timber volume

Function no.	Function name	Reference(s)
[1]	Logistic: $Y = a\,[1 + \exp(b - cX)]^{-1}$	Hutchinson 1978
[2]	Gompertz: $Y = a \exp(-b.e^{-cX})$	Zullinger *et al.* 1984
[3]	Chapman-Richards: $Y = a\,[1 - \exp(-bX)]^{c}$	Richards 1959
[4]	Weibull: $Y = a \exp\,[1 - b.\exp(-cX^{d})]$	Yang *et al*. 1978
[5]	Sloboda: $Y = a \exp\,[-b.\exp(-cX^{d})]$	Zeide 1993

*Short note

[1]Scientist (Sr. Scale) (e mail: rhrizvi@mailcan.com),

[2]Professor and Head, Department of Statistics, Dr B R A University, Agra 282 004, Uttar Pradesh

[3]Senior Scientist (e mail: handaarun@mailcan.com), NRC for Agroforestry, Jhansi 284 003

linear regression procedure of SYSTAT 11.0 was applied and the parameters were estimated using least square method (Engelman 2004). Statistical criteria such as root mean square error (RMSE), adjusted R^2, asymptotic standard error (ASE) of parameters' estimates were used for judging the goodness of fit. Modified error index (MEI), a weighed average of absolute errors was applied for the selection and/or assessment of final selected model (Pandey *et al*. 2001), which is defined below:

$$MEI = \sum W_i\,[e_i]/\sum W_i$$

where, W_i, weight associated with volume of ith tree,

$e_i = | O_i - E_i |$, absolute error in prediction,

O_i – observed volume (m^3),

E_i – estimated volume (m^3).

While selecting an appropriate model, one should observe the adjusted R^2 with modified error index. Model validation was also done through graphical and statistical methods as suggested by Mayer and Butler (1993), Reynolds and Chung (1986).

Model efficiency (ME) was also computed for the final selected models whose formula is given below:

$$ME = 1 - \{ \sum (P_i - O_i)^2/\sum (O_i - \hat{O})^2 \}$$

where P_i, predicted volume (m^3) and O_i, observed volume (m^3).

Five non-linear functions, viz Logistic, Gompertz, Chapman-Richards, Weibull and Sloboda (Table 1) were fitted for timber volume of *P. deltoides* tree. First three are 3 parameters functions whereas last 2 are 4 parameters functions. The summary statistics of the data sets used for construction and validation of models is presented in Table 2. Tree height ranged from 13.4 to 23.2 m with mean 17.86 m for construction data, whereas it ranged from 17.60 to 24.95 m with mean of 21.89 m for validation data. The diameter at breast height varied from 16.56 to 32.17 cm for construction data and from 23.57 to 35.03 cm for validation data set. Timber volume (over bark) ranged from 0.094 to 0.436 m^3/tree for construction data and from 0.243 to 0.632 m^3/tree for validation data set. The Pearson correlation coefficients were found significantly high between independent variable, i e timber volume and dependent variables, i e tree height, diameter at breast height and D^2H which come out to be 0.970, 0.962 and 0.987, respectively.

The root mean square error (RMSE), adjusted R^2 and asymptotic standard error (ASE) of parameters' estimates for the fitted functions are presented in Table 3. The RMSE was quite low for all the functions ranging from 0.00014 to 0.00021 and values of adj. R^2 was found to be more than 0.95 for all the functions with highest value of 0.954 for functions [3] and [4]. It is also observed from the Table that estimate of all parameters were significant except parameter 'b' of function [4] and parameter 'c' of function [5] as their ASE was very high. Therefore, fitted functions [4] and [5] may not be selected on the basis of ASE. Moreover, the values of RMSE for remaining functions were comparatively low and also there was not much difference in values of adj. R^2, so the selection of best fitted model needs further validation. For this purpose, another data set was used for predicting volume (over bark). Since the variability in D/H was higher than that of H/D, so Di/Hi was taken as weight (Wi) for the ith tree and modified error index (MEI) were computed and given here. The value of MEI was lower for model 2 than other 3 models and also value of adj. R^2 was at par with model 3. Fig 1 also depicts the goodness of fit of this model. Thus model 2, i e Gompertz model adjudged best among 3 models fitted using 'D' as explanatory variable.

Fitted model	Adj. R^2	MEI
$V = 0.622\,(1+ e^{(4.039-0.147*D)})^{-1}$	0.951	0.034
$V = 1.002\,\exp(-6.355\,e^{-0.0622*D})$	0.953	0.029
$V = 1.567\,(1- e^{-0.034*D})^{1/1-0.697}$	0.954	0.035

Same non-linear functions were fitted using D^2H as explanatory variable for timber volume (over bark) of poplar trees. The fit statistics obtained for these functions are given in Table 4. The RMSE for all functions were significantly low and ranged from 0.00010 to 0.00016 for functions [3] and [1], respectively. The values of adj. R^2 were found to be significantly high with highest value of 0.984 for functions [3], [4] and [5]. This indicates that about 98.4% variation in

Table 2 Summary statistics for construction and validation data of *Populus deltoides*

Statistics	Construction data				Validation data			
	Tree height (m)	DBH (cm)	D^2H (m^3)	VOB (m^3)	Tree height (m)	DBH (cm)	D^2H (m^3)	VOB (m^3)
No. of cases	40	40	40	40	20	20	20	20
Minimum	13.400	16.560	0.391	0.094	17.600	23.570	0.978	0.243
Maximum	23.200	32.170	2.401	0.436	24.950	35.030	3.062	0.632
Mean	17.486	23.302	1.026	0.226	21.897	31.086	2.167	0.420
Std error ±	0.396	0.673	0.080	0.014	0.443	0.688	0.125	0.023
CV (%)	14.30	18.30	49.60	39.10	9.00	9.90	25.90	24.40
Skewness	0.318	0.162	0.890	0.394	–0.459	–1.178	–0.477	0.371
Kurtosis	–0.397	–0.663	0.518	–0.259	–0.356	1.324	–0.060	–0.159

DBH, diameter at breast height; VOB, volume over bark

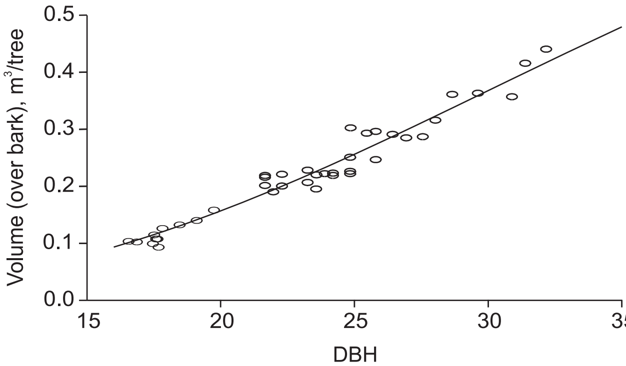

Fig 1 Fitted Gompertz function for timber volume using DBH

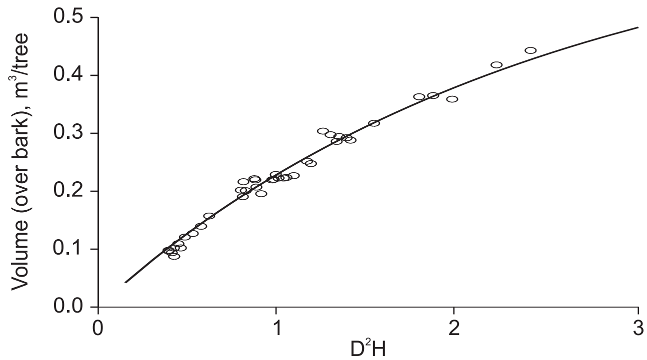

Fig 2 Fitted Chapman-Richard function using D^2H

Fitted Model	Adj. R^2	MEI
$V = 0.50\,(1+ \exp\,(1.767–1.543*D^2H))^{-1}$	0.970	0.0306
$V = 0.488 \exp\,(–2.366\, e^{-1.137*D2H})$	0.980	0.0339
$V = 0.705\,(1– \exp\,(–0.394*D^2H))^{0.976}$	0.984	0.0230

volume of trees is explained by these fitted functions. It can be observed from Table that estimates of parameter ‘b’ for functions [4] and [5] are non-significant, as their ASE was high as compared to other parameters. All other functions have low values of ASE indicating parameters’ estimates were significant.

The functions [4] and [5] did not satisfy the criteria of ASE though they had highest values of adj. R^2. The remaining 3 functions had very low value of RMSE and high value of adj. R^2, so the selection of best one needs further validation. For this purpose, volume was predicted for an independent data set and the MEI for the fitted models were computed and shown here. The model no. 3 had the lowest value of MEI, i e 0.023 and the highest value of adj. R^2, i e 0.984. Fitted Chapman-Richards function for timber volume showed goodness of fit of this model (Fig 2). Thus the Chapman-Richards model adjudged best among 3 models fitted using D^2H as explanatory variable.

The Gompertz and Chapman-Richards models fitted using explanatory variables ‘D’ and ‘D^2H’ respectively were applied on another data set for examining its prediction ability. In case of Gompertz model, the mean absolute error (MAE) in prediction comes out to be 0.029, which indicate that an error of 0.029 m^3 may be committed by this model in predictions of timber volume. The model efficiency was also computed which comes out to be 88.1%. Hence developed

Table 3 Fit statistics for timber volume equations fitted using ‘DBH’

F. No.	RMSE	Adj. R^2	Parameters’ estimates			
			a	b	c	d
[1]	0.00021	0.951	0.622 (0.103)	4.039 (0.208)	0.147 (0.019)	
[2]	0.00019	0.953	1.002 (0.363)	6.355 (0.891)	0.062 (0.016)	
[3]	0.00015	0.954	1.567 (1.360)	0.034 (0.025)	3.003 (0.107)	
[4]	0.00014	0.954	1.661 (56.378)	75.000 (7062.95)	1.603 (82.765)	0.221 (8.203)
[5]	0.00017	0.953	0.010 (0.185)	–5.609 (25.163)	23.807 (372.956)	–1.172 (4.188)

Figures in parentheses indicates the standard errors for the parameters’ estimates

Table 4 RMSE, adjusted R^2 and ASE of parameters’ estimates for fitted functions using ‘D^2H’

F. No.	RMSE	Adj. R^2	Parameters’ estimates			
			a	b	c	d
[1]	0.00016	0.970	0.500 (0.027)	1.767 (0.061)	1.543 (0.119)	
[2]	0.00014	0.980	0.488 (0.023)	2.366 (0.084)	1.737 (0.090)	
[3]	0.00011	0.984	0.691 (0.115)	0.394 (0.128)	0.976 (0.087)	
[4]	0.00010	0.984	0.626 (8.414)	20.445 (741.974)	2.330 (23.133)	0.156 (2.019)
[5]	0.00012	0.984	0.001 (0.038)	–7.810 (40.439)	0.371 (1.578)	–0.395 (1.011)

Figures in parentheses indicates the standard errors for the parameters’ estimates model, i e V = 1.002 exp (–6.355 $e^{-0.062*D}$) may be used for predicting timber volume (over bark) of *P. deltoides* using DBH as explanatory variable.

In case of Chapman-Richards model, the predictions were found to be very close to the actual ones. The mean absolute error of predictions comes out to be 0.023 indicating that only an error of 0.023 m^3 can be committed by this model in volume. High model efficiency of 91.6% was also found for this model. Hence the developed model, ie V = 0.705 [1– exp (–0.394 × D^2H)]$^{0.976}$ may be used for estimating timber volume (over bark) of poplar tree in Haryana region.

SUMMARY

Sixty *Populus deltoides* trees of ages 6, 7 and 8 years were selected from agroforestry plantations in Haryana. The growth (height, bole height and dbh) and timber volume (over bark) data was recorded/computed for these trees. The 5 non-linear functions, viz Logistic, Gompertz, Chapman-Richards, Weibull and Sloboda were fitted using 'D' and 'D^2H' as explanatory variables; where D, diameter at breast height (cm), H, height of tree (m). These fitted models were validated statistically and graphically using data splitting procedure. The Gompertz model, i e V = 1.002 exp (–6.355 $e^{-0.062*D}$), where V-timber volume (m^3), was adjudged best for predicting the timber volume using 'D' with mean absolute error of 0.029 m^3. On the other hand, the Chapman-Richards model, i e V = 0.705 [1–exp (–0.394×D^2H)] $^{0.976}$ found best among 5 models fitted using 'D^2H' with mean absolute error of only 0.023 m^3. Hence the proposed models may be used for predicting the timber volume (over bark) of *P. deltoides* tree in Haryana region.

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