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Biomass estimation of *Acacia catechu* using statistical modelling

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Abstract

Acacia catechu is a very dominant and popular fodder tree in the dry and semi-arid part of central India. The aim of the present study was to find out suitable predictor variables for total tree biomass relationship and to fit popular nonlinear models for the total biomass of *Acacia catechu.* The selection of sample sites were based on NDVI generated through IRSP6LISS-III imagery of four districts of Uttar Pradesh part of Bundelkhand namely Jhansi, Mahoba, Hamirpur and Lalitpur. The dataset contained 220 trees with DBH ranging from 3 cm to 49 cm. Correlation analysis between calculated total biomass and different biometric parameters of individual tree were first performed using CD, H, DBH and D^2H as explanatory variables. The variable DBH was found to be highly correlated with the total biomass, hence models were fitted using DBH as independent variable. The nonlinear models tried in this study include Allometric, Gompertz, Logistic, Weibull and Chapman-Richards models. Independent datasets were used for construction and validation of models. The Gompertz model was found to be the best fit (R^2=0.94, RMSE=57.2). The fitted model was then validated using model diagnostics and statistical validation techniques and tested with an independent dataset to see the accuracy of prediction.

Keywords: *Acacia catechu*, Correlation, Fodder tree, Nonlinear models, Semi-arid region

Abbreviations: CBH: Circumference at breast height; **CD**: Collar diameter; **H**: Height of tree; **DBH**: Diameter at breast height; **NDVI:** Normalised difference vegetative index

Introduction

Acacia catechu is widely distributed throughout a large part of India except the most humid, cold and the driest regions. This is a large genus of about 800 species of trees, shrubs and climbers. In India there are about 22 indigenous species distributed throughout plains and some in hilly regions and some others are being introduced to India (Gupta *et al.*, 2012). It is essentially a tree of comparatively dry regions. These are multipurpose and nitrogen fixing trees that play an important role in the arid and semi-arid regions of India. Generally *A. catechu* is tolerant to different adverse soil and climatic conditions and more remunerative than most other arable crops in the long run. Hence, it is appropriate to integrate *Acacia* in these eroded lands so as to bring the land under tree cover for economic and ecological benefits (Devaranavadgi *et al.*, 2010). Besides its commercial importance, it is equally significant for the people particularly rural communities living in the vicinity of *A. catechu* forests as it is a secondary source of income to them. To a certain extent, these people are dependent on this plant to fulfil their day to day need of fuel, fodder, building material and others (Singh and Lal, 2006) and also in this part of India, it is considered to be a good fodder tree and is extensively lopped to feed goats and cattle. For leaf fodder, finger-thick branches are lopped usually before main leaf fall occurs. The leaves contain 13.03-18.72% crude protein, 47-51% N free extract and 0.14-0.17% phosphorus. Total digestible nutrients are 46.33 kg of dry material and nutritive ratio is 15.0. The digestibility values are moderately high which shows that the leaves are good feed for cattle on the basis of crude protein, crude fibre and tannin contents. The leaf fodder from *Acacia catechu* is rated as good.

Sustainable management of *A. Catechu* in semi-arid part of the country is a priority task. The main purpose of this study was to find out the most suitable regressor amongst different tree parameters and to develop statistical model for the biomass to have an idea of total fodder or timber production from this tree. This study may prove useful in any future large scale project aiming at developing database and planning technique used for managing *Acacia* wood lands of the semi-arid region.

Materials and Methods

Study area: The study was conducted on central high land physiographic zone of Uttar Pradesh, lying between

21°17' to 26° 52' N latitudes and 74°08' to 82° 49' E longitudes and covers part of Bundelkhand region in Uttar Pradesh. The dataset used in the present study contains different biometric characters like CD, H, DBH and D^2H. The sites were selected for the collection of data, using NDVI map based on IRSP6LISS-III imagery of 2010 & 2011 covering four districts of Uttar Pradesh namely Jhansi, Mahoba, Hamirpur and Lalitpur. The study area of these four districts mainly exhibits dominance of clay loam soil (Jhansi, Hamirpur and Lalitpur) and forest type is mixed type (Table 1).

Biomass estimation: Indian laws do not permit to cut or harvest any plants, so direct or destructive methods of estimating biomass were not possible. Therefore, indirect or non-destructive method was the only alternative left for biomass estimation by combination of visual or assumption methods. The volumes over bark of different parts of the standing tree were separately calculated so that we can achieve total volume over bark of the standing tree by adding them. In total 220 *Acacia* trees were sampled and data on several physiological parameters like diameter at breast height, basal diameter, tree height, forking height, collar diameter etc. were collected. The volume of a single-stemmed tree is between that of a cone and a cylinder, with tree volume often lying between 0.40 and 0.45 times that of an equivalent cylinder. Using a value of 0.42, for example, an equation can be developed to estimate cubic volume of wood (Gertner, 1991). Then total volume over bark of the standing tree bole was calculated by adding the volume of these different parts. The stem wood biomass was calculated by multiplying volume with wood density (0.88 gm/cm^3) of *Acacia catechu* (Zanne *et al*., 2009). The stem wood biomass was then expanded to total above ground biomass of tree including leaves, twigs, branches, bole and bark using (Priyanka *et al.,* 2013) biomass expansion factor (BEF).

Total above ground biomass = Stem wood volume x wood density x BEF

The mean BEF value of 1.5 was used for this study as prescribed by Brown and Luge (1992). The below ground biomass was calculated by using simple default value of 25% (for hardwood species) of the total above ground biomass as recommended by Simon *et al.* (2006).

Model fitting: The dataset was then divided into two independent groups. One part (80%) of the data was used to develop the model and the rest (20%) was to validate that. Snee (1977) recommended that the data splitting is an effective technique of model validation when it is not practical to collect new set of data. The five nonlinear models were tried separately to regress the total calculated biomass (Table 2). Usefulness of allometric model to estimate small diameter trees like *Acacia* was previously studied by researchers (Singh *et al.,* 2011), so it was also included for testing in present study. The model fitting using nonlinear regression procedure was performed using SAS 9.3 and the parameters were estimated using least square method (Wilkinson *et al*., 1996). The model with highest R^2 and minimum root mean square error (RMSE) was selected for testing and validation. Several model diagnostics and statistical validation techniques were followed for the selection and assessment of final selected model.

Table 1. Location, soil type and forest structure details of all four sites

Sites	Latitude	Longitude	Altitude(m)	Slope (%)	Forest type	Soil texture	No. of trees
Jhansi	$25^0$36'-$26^0$34'	$71^0$19'-$01^0$67'	165.45	25	Mixed	Clay loam	58
Mahoba	$25^0$18'-$14^0$04'	$79^0$47'-$54^0$17'	185.00	2	Mixed	Gravel red	73
Hamirpur	$25^0$32'-$27^0$12'	$79^0$25'-$34^0$81'	154.53	15	Mixed	Clay loam	63
Lalitpur	$24^0$22'-$42^0$91'	$78^0$32'-$50^0$40'	456.00	2	Mixed	Clay loam	26

Table 2. Nonlinear functions used in the study and their fit statistics

Model	Equation	References	R^2	RMSE
Gompertz	$Y = [c \exp(-b \exp(-aX)] + e$	Causton & Venus (1981); Zullinger *et al.* (1984)	0.940	57.206
Logistic	$Y = [c/(1 + b \exp(-aX)] + e$	Hutchinson (1978)	0.910	58.798
Allometric	$Y = aX^b + e$	Schreuder *et al.*(1979)	0.926	64.803
Weibull	$Y = [a - b \exp(-cX^d)] + e$	Yang *et al.* (1978)	0.788	167.381
Chapman-Richards	$Y = [a(1 - \exp(-bx)^d] + e$	Richards (1959)	Fail to converge	

Table 3. Descriptive statistics of tree samples collected

Parameter	Maximum	Minimum	Mean	Standard deviation	S.E of mean	CV (%)
DBH (cm)	49.02	3.38	65.09	0.05	0.01	51.85
Total biomass(kg)	1230.63	9.59	187.18	215.64	14.53	115.20
Height (m)	12.50	1.50	3.45	7.79	0.05	23.11
Basal area (m^2)	0.94	0.01	0.10	0.12	0.00	117.66
CBH (cm)	108.50	10.60	31.68	16.48	1.11	52.02

Results and Discussion

Selection of effect variable: The descriptive statistics are given in Table 3. The height of sampled trees varies from 1.50 to 12.50 m, the coefficient of variation for tree height was 23 percent; DBH varies from 3.3 to 49 cm, basal area from 0.01 to 0.94 m^2 and calculated total biomass ranged from 9.59 kg to 1230.63 kg with a very high CV. For model development along with the tree parameters mentioned in the above table one additional combined variable D^2H was derived using DBH and tree height as it was found very useful for regressing tree biomass in various earlier studies (Sharma, 1978; Tandon *et al.*, 1988; Jain *et al.*, 1991; Rizvi *et al.,* 2008).The correlation study was performed to find out the parameters which have the highest correlation with total tree biomass. The Pearson correlation coefficients clearly show that DBH is the most suitable variable for regressing total biomass of *Acacia catechu* (Table 4).

Comparing models: For fitting regression models, the normality test of the response variable was done using Shapiro Wilk test and the result showed a very high p value (<0.001) suggesting rejection of the assumption of normality of response variable. So, the response variable *i.e.* total biomass was log transformed to eliminate the problem of non-normality of the data. Total biomass of *Acacia* was calculated using diameter at breast height as independent variable. Five nonlinear functions given in Table 2 were tried to estimate the biomass. Each function is given with corresponding R^2 and RMSE values to make a comparison between the models (Table 2). It can be observed from the table that the R^2 is highest for Gompertz model (94%) and lowest for Weibull model (78%) and these two models also have the lowest and highest RMSE respectively. So, on the basis of these two criteria we conclude that Gompertz model is the best fitted one among the five models. Parameters estimated for Gompertz model (Table 5) showed very high correlation between them (>0.80), so here Levenberg-Marquardt method was used as the fitting algorithm (SAS, 2011). The expression for the estimated model is: Biomass =1531.86(-6.29 exp (-9.61 * DBH)) and the fit plot is given in figure 1. The asymptotic 95% confidence intervals for Gompertz model parameters are calculated and in two-sided test at 5% level of confidence, all the three parameters lie within the 95% confidence limits.

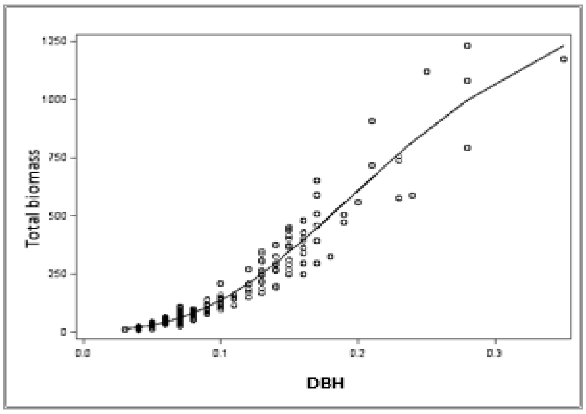

Fig 1. Fit plot for Gompertz model for total biomass using DBH

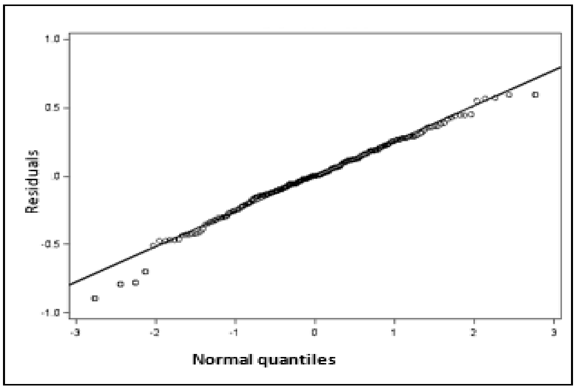

Fig 2. Q-Q Plot of residuals

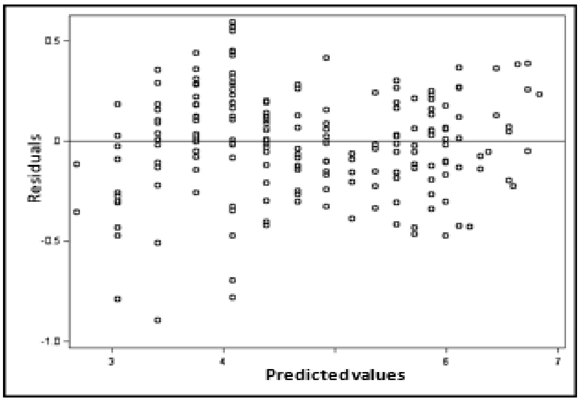

Fig 3. Residuals plotted against predicted values

Model validation: To check the model adequacy, validity of assumptions of regression analysis has been checked here using some diagnostic methods primarily based on the study of model residuals. The normality assumption of the residuals was tested with a normal quantile graph using the residuals. The Q-Q Plot (Fig. 2) showed a slight, negligible deviation from normality near both the tails. To check the homoscedasticity of the residuals, residuals are plotted against dependent (Fig. 3) and independent variables (Fig. 4). The graphs revealing no pattern as such confirmed absence of heteroscedasticity. Presence of autocorrelation amongst the errors was tested using Durbin-Watson statistic (Montgomery *et al.,* 2003). The value of this statistic was found to be 1.15, which is less than 2 indicating the absence of any autocorrelation.

Therefore all these diagnostics gave satisfactory results for fitting the proposed model. Finally the model tested against the dataset kept for validation. The predicted values closely matched the observed total biomass values indicating the accuracy of prediction.

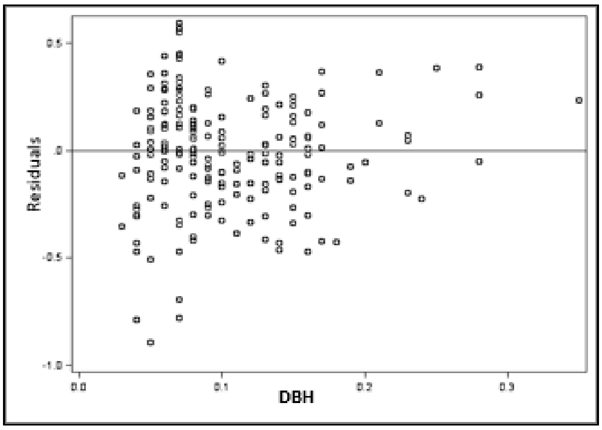

Fig 4. Residuals plotted against independent variable

Table 4. Pearson correlation coefficients

	CBH	Tree-height	DBH	D^2H	Basal area
Total biomass	0.91	0.35	0.95	0.93	0.93

Table 5. Parameter estimates of the best fit model

Parameter	Estimate	Approx. Std. Error	Approximate 95 % confidence limits	
a	9.60	0.56	8.49	10.72
b	6.29	0.28	5.74	6.85
c	1531.90	98.11	1338.50	1725.20

Conclusion

The present study was conducted on *Acacia catechu* to find out most suitable predictor variables and producing a general non-site-specific biomass relationship applicable to diverse stands of *Acacia catechu* across the study area without harvesting any tree. Biomass estimation was done using geometric calculation of standing trees without harvesting them and from popular nonlinear models, the Gompertz model was found to be the best fit (R^2=0.94, RMSE=57.2). The suggested model was judged on different statistical criteria and diagnostics to confirm its validity and also tested on an independent dataset to test its accuracy of prediction. Such type of equation will be of much importance for foresters and merchants involved in marketing several products from this tree. This model may be used in other similar areas with suitable modification based on actual ground data.

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