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Predictive model for fibre yield estimation of *tossa* jute (*Corchorus olitorius*) in India

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ABSTRACT

The present study explores the possibility of developing statistical models for prediction of dry fibre yield of *tossa* jute (*Corchorus olitorius*) in India. Sixty plants of 110 days age were randomly selected from the study area, and their basal diameter and dry fibre yield were measured for analysis and fitting of models. Basal diameter was found to be a very good predictor of dry fibre yield and was included in the model. Various functions (linear, monomolecular, logistic, Gompertz, allometric, Chapman) were fitted to estimate a relationship between dry fibre yield and basal diameter of the plant. The adjusted R^2 values were > 0.72 for all six models and Chapman model ($Y = k \times (1\text{-exp}(-a \times X))^b$ was found as best performing with highest R^2 (0.77) lowest Akaike's information criterion (AIC) value (68.40) . The paired *t* statistics value between observed and predicted fibre yield was found non-significant (p>0.05), which clearly indicates the validity of the model. The models developed in the present study will be of immense help to the jute cultivators in estimating dry fibre yield before harvesting, by simply measuring the basal diameter values of the jute plants. The estimated fibre yield is 34 q/ha with average basal diameter of 1.3 cm and 4 lakh/ha plant density.

Keywords: Basal diameter, Chapman model, *Corchorus olitorius,* Fibre yield, Predictive models

Jute, traditionally grown as rainfed monocrop, is one of the most affordable natural fibres and economically important crops of India and Bangladesh. In India, jute crop provides livelihood security to about four million farm families in the states of West Bengal, Bihar, Assam and Odisha (Mahapatra *et al*. 2012). India is the largest producer of jute, followed by Bangladesh, jointly contributing about 95% of world jute; with acreage of 769928 and 73770 ha and productivity of 25.54 and 20.28 q/ha during 2017, respectively (FAO 2019). Fibre yield estimation is helpful to farmers and policy makers for overall productivity of the land and generation of higher revenue. This estimation also aids in planning, formulation and implementation of policies related to jute. Thus, pre-harvest prediction of jute fibre yield is required when crop is still standing in the field. In India, various linear and non-linear models were developed for estimating biomass for short rotation and timber species such as *Populus deltoides* (Ajit *et al*. 2011, Gupta *et al.* 2011, Rizvi *et al*. 2011), *Dalbergia sissoo* (Bohre *et al*. 2012), *Tectona grandis* (Buvaneswaran *et al*. 2006), bamboo (Kaushal *et al*. 2016), and *Psidium guajava* (Rathore *et al*. 2018). In Eastern India, despite economic importance of jute, only a few works had been attempted on dry biomass and yield estimation in jute. It is established that both plant height and basal diameter of jute has direct significant relationship with fibre yield of both the species of jute (Palit 1997). Jute being a tall plant, measuring plant height particularly at the later growth stages is difficult and also large numbers of plants are wasted in the process. On the other hand, unlimited number of observations can be taken in case basal diameter measurement throughout the growth period without cutting a single plant, and may be more acceptable to the users. Therefore, the present study was undertaken to develop predictive models for estimating dry fibre yield of *tossa* jute (*Corchorus olitorius*) in Eastern region of Indo-Gangetic plains for the benefit of the cultivators as well as the policy makers.

MATERIALS AND METHODS

The study was conducted during 2018–19 at ICAR-Central Research Institute for Jute and Allied Fibres, Barrackpore, Kolkata (West Bengal) under All India Network Project on Jute and Allied Fibres. The experimental site is located at 22º45'N latitude and 88º26' E longitude at an altitude of 9 m above the mean sea level, with mean annual precipitation of around 1500 mm, major portion

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of which occurs during June to September, and the mean maximum and minimum temperature of the location are 31.1 and 21°C, respectively. The soil of the experimental site was non-saline (EC 0.23 dS/m), moderately deep, well drained and sandy clay loam in texture, with pH, initial oxidizable soil organic carbon (OC), soil available alkaline potassium permanganate ($KMnO_4$) nitrogen, Olsen phosphorus (P) and extractable ammonium acetate (NH_4OAc) and potassium (K) levels being 7.1, 0.63%, 273, 44.5 and 196 kg/ ha, respectively.

Crop management: Jute crop was sown with receipt of the first showers in mid of March to first week of April during both years at a spacing of 25 cm × 5-7 cm with a seed rate of 4-6 kg/ha. At 110 days after sowing, 60 random plant samples were harvested and observation was recorded on basal stem diameter (BD) in mm and fibre yield (g/plant). Basal diameter was measured 3-5 cm above ground level. Recommended practices such as weeding, irrigation and plant protection measures were followed.

Model fitting and validation: Different linear and non-linear models were fitted to establish the relationship between dry fibre yield (g/plant) and basal diameter (cm). A scatter plot of total dry fibre yield vs basal diameter was initially drawn to get an idea of the shape of the function to be fitted on the data. Scatter plot revealed that the candidate functions usually adopted for modelling dry fibre yield-BD curves, viz. linear, monomolecular, logistic, Gompertz, Allometric, Chapman will fit well in the observed dataset. Equation performance was monitored using goodness-of-fit statistics, namely the coefficient of determination (R^2) and standard error (SE) of estimates. The original dataset of 60 plants were divided into two mutually exclusive and independent datasets and pseudo-exclusive datasets; 45 data points were used for model fitting and 15 for validating the models. Residuals for the estimated model were tested for normality using the Anderson–Darling test and for independence using the run test. For statistical validation of the model, paired t test between the actual and the model predicted values were done with the null hypothesis that there is no difference between observed and predicted mean values. The basal diameter of values of 110 days old *tossa* jute plant can used for estimation of dry fibre yield. SAS 9.3 software package was used to for computation of descriptive statistics, fitting of different nonlinear models and their validation.

RESULTS AND DISCUSSION

Wide range of variation was observed with respect to basal diameter and dry fibre yield of the harvested plant samples. The basal diameter of the plant samples varied from 0.85 to 1.86 cm with a mean value of 1.35 cm. Dry fibre yield ranged from 3.07 to 22.79 g/plant with mean value of 18.54 g/plant for the entire dataset. The dry fibre yield is affected by many factors like climatic, edaphic factors, soil and nutrient management practices, retting practices and jute plant density. Studies also indicated that 25-30 cm × 6-8 cm spacing combination favours even spatial distribution of plants and thereby better utilization of resources by jute plants and higher fibre yield (Ghorai *et al*. 2008). Selection of model for estimation of dry fibre yield is very important in quantifying yield. In the present study, only one independent variable, i.e. basal diameter has been taken into consideration which was found to be a good predictor of dry fibre yield (R^2> 0.72 for all models) and plant height was not included in the model. Equation for estimating dry fibre yield using one independent variable is simple, economical and rapid method as they do not require additional height measurement in the field for its application. A number of studies also reported that predictive models using one independent variable are simple, time efficient and economical too (Segura *et al*. 2006, Nath *et al*. 2009). Parameter estimates of all the six models along with other related statistics fitted on estimation dataset are presented in Table 1. All the models explained more than 70% variability in measured biomass. The adjusted R^2 (observed vs predicted) values was maximum for Chapman

Table 1 Parameter estimate of various models fitted on 75% data set for total dry fibre

Model	Parameter estimates	*a*	*b*	*k*	Adjusted R^2	Reduced Chi-square	AIC
Linear	$Y = a + b \times X$	-12.41 (-2.21)	16.28 (-1.58)	-	0.73	5.56	69.05
Monomolecular	$Y = 1-(1-a)\times exp(-b\times X)$	1.82 (-0.22)	-1.69 (-0.17)	-	0.72	5.62	70.58
Logistic	$Y=k/(1+(k/a-1) \times exp(-b\times X))$	0.44 (-0.40)	2.50 (-0.86)	31.19 -17.04	0.75	5.42	70.73
Gompertz	$Y=k \times exp(-b \times exp(-a\times X))$	0.96 (-0.76)	6.67 (-2.23)	56.86 -72.35	0.75	5.40	70.39
Allometric	$Y= a \times X^b$	4.65 (-0.49)	2.28 (-0.23)	-	0.76	5.39	70.30
Chapman	$Y = k \times (1-exp(-a\times X))^b$	0.44 (-1.24)	3.19 (-3.20)	121.8 -492.3	0.77	5.27	68.40

X: Basal diameter; AIC: Akaike's information criterion model. Chapman model with lowest Akaike's information criterion *(AIC)* and reduced chi-square values of 68.40 and 5.27 fulfils the model fitting criterions to the best possible extent followed by linear model (*AIC*=69.05, reduced chi-square =5.29). Linear models estimated negative values of predicted biomass when the values of basal diameter are very low. These results are in line with the findings of Verma *et al.* (2014) and Rathore *et al*. (2018).

Validation of the six fitted model have been done using the remaining 25% data set . Mean residual was lowest (1.73) in both Chapman and Gompertz model followed by logistic model (1.74). The paired *t* - test between observed vs. predicted fibre yield came out to be non-sginificant (P>0.05) in all the six model with highest p value in Allometric model (0.66) followed by Chapman model (P=0.60) compared to the other model. Linear regression between predicted an observed value (predicted = $a + b \times$ observed) was carried out where observed and predicted values were tested for zero intercept and unit slope. A model with lowest and nearer to zero value for '*a*' and '*b*' value closer to one is the best validated model (Ajit *et al*. 2011). For chapman model, *a* value came out to be minimum (1.99) followed by Gompertz and allometric model (2.11) whereas *b* value was maximum in Allometric (0.77) mole followed by Chapman and Monomolicular and Gompertz model (0.76). Accordingly, out of the six models, chapman model, was selected for predicting jute fibre yield using basal diameter as explanatory variable as it met all the required criteria in both fitting and validation stage. Verma *et al*. (2014), Kaushal *et al*. (2016), Rathore *et al*. (2018) and Tanwar *et al.* (2019) reported that allometric models were best performing fulfilling the criteria of validation in different species across Indian sub-continent.

As overall, chapman model came out to be the best model in both fitting and validation criteria, its residuals have been tested for independence and normality for statistical validation. The test statistic for Anderson–Darling test was 1.49 (P=0.16) which indicates the acceptance of the null hypothesis. Assumptions of independent and normally distribution of errors with mean zero and constant variance were evaluated through relevant graphs (Fig 1). The plots of residuals against the explanatory variable (basal diameter) as well as estimates for Chapman model ensure that the residuals are independently distributed. It ensures that the residuals are not continuously over/under estimated for total dry fibre yield and the plot of residual against estimate indicated that the residual have constant variance. The auto correlation plot of the residuals ensures that the residuals are not correlated. Chapman model was found to be the best performing and therefore used to determine relationship between fibre yield using basal diameter as explanatory variable (Fig 2). Therefore, Chapman model

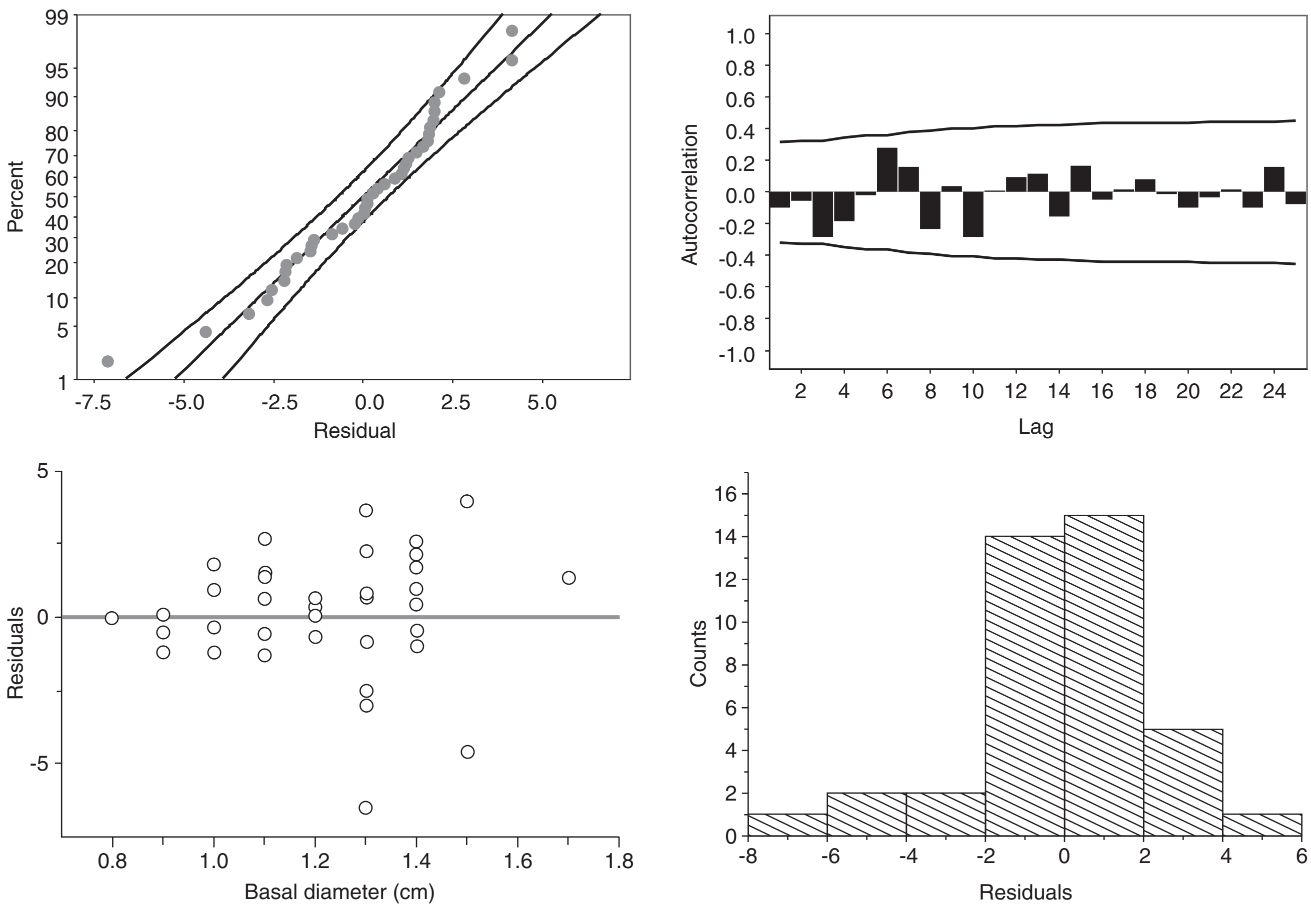

Fig 1 Plots of residual against the values of predicted and explanatory variable.

Table 2 Fibre yield (q/ ha) estimates using developed model for *tossa* jute

		Basal diameter (cm)								
		1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8
Plant density (l/ha)	2.5	11.12	14.13	17.49	21.18	25.19	29.49	34.06	38.86	43.87
	3.0	13.34	16.95	20.99	25.42	30.23	35.39	40.87	46.63	52.65
	3.5	15.57	19.78	24.48	29.66	35.27	41.29	47.68	54.40	61.42
	4.0	17.79	22.60	27.98	33.90	40.31	47.19	54.49	62.17	
	4.5	20.01	25.43	31.48	38.13	45.35	53.09	61.30		
	5.0	22.24	28.25	34.98	42.37	50.39	58.99			
	5.5	24.46	31.08	38.47	46.61	55.43				
	6.0	26.69	33.90	41.97	50.84	60.47				

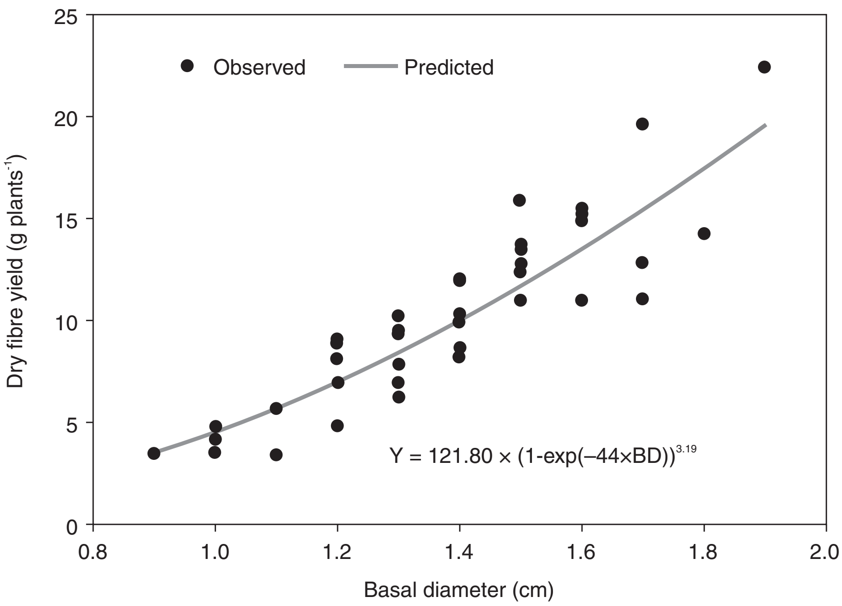

Fig 2 Chapman model fitted to the observed dataset of dry fibre yield vs basal diameter.

was selected to establish a relationship between dry fibre yield and basal diameter, and this model was used to predict the dry fibre yield.

The total fibre yield can vary from 13.34 to 35.39 q/ha under average plant density of 3 lakh/ha for jute plant with basal diameter 1.0 to 1.5 cm. The analysis revealed that, the estimated fibre yield of 34 q/ha can be obtained with average basal diameter of 1.3 cm measured form 90 days old plant and 4 lakh/ha plant density (Table 2). The earlier works also revealed that plant height and basal diameter are significantly related to fibre yield of jute. Palit *et al.* (1997) had established distinct power relationship of plant height of jute with biomass and fibre yield of the crop. The plant height of *tossa* jute at 55 days after sowing was found to have significant correlation with biomass and fibre yield (Mitra *et al*. 2008).

Different linear and non-linear models were fitted for estimation of jute fibre yield using basal diameter as independent variable in New Gangetic alluvial soil of the country. In the present study, predictive models were developed for the first time in order to estimate dry fibre yield of jute. Validation of the models was undertaken to find the reliability of these models. Out of six different models attempted, Chapman model fulfils the validation criterion to the best possible extent and is considered as best performing. Further, it is concluded that Chapman model developed from this study can be used in eastern Indo-Gangetic plains, where jute is widely grown and it may provide useful information on jute yield to jute growers and policy makers. This model could be useful in estimating jute fibre yield in similar site conditions.

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