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Growth and Yield Prediction Models for *Acacia auriculiformis* (Akashmoni) Grown in the Plantations of Bangladesh

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Abstract

Akashmoni (*Acacia auriculiformis* A. Cunn ex Benth, family Leguminnosae) is a promising fast-growing tree species for timber use. This species of tree has occupied a unique position due to furniture manufacturing and construction work. Growth and yield of the species in Bangladesh are scientifically unknown. Therefore, the necessity of growth and yield models for the species was felt for the scientific management of the forest. The present study was conducted to derive mathematical models for growth and yield of this species in Bangladesh based on site indices. The models were derived by establishing Permanent Sample Plots (PSPs) and Temporary Sample Plots (TSPs) with an area of 0.02 ha and a circular or rectangular shape. Diameter at breast height and total height of all trees in the plots were measured by PSPs for seven consecutive years. The stepwise procedure and all probable combinations of the independent variables were used to select the most appropriate models, provided that the statistical and biological requirements were met. Models were selected to estimate the stocking ha^{-1} of the canopy, the mean height of the canopy, the diameter of the canopy, the basal area of the canopy ha^{-1}, the yield of the canopy volume ha^{-1} and the aboveground biomass of the canopy ha^{-1} Estimate Akahmoni. The yield forecast models derived in the study could be used satisfactorily for Akashmoni with a stand age of 4 to 17 years and site indices of 9 to 21 meters based on a base age of 12 years. Extrapolation over this data range is not recommended. The selected models were verified against separate datasets using chi-square test, paired t-test, percent absolute deviation, and 45-degree line test. The biological principle of the model development was checked. The results suggest that the models were statistically and biologically acceptable. The developed models could safely be used for forecasting growth and yield of Akashmoni.

Keywords: *Acacia auriculiformis*; Growth and yield; prediction; plantation and Bangladesh

Introduction

The components of growth and yield models are the known and measurable variables that are evaluated using biological theories and mathematical language relevant to living systems. Biological theory and mathematical language help isolate complex tree interactions, individually or in combination, that are difficult to verify, and then assume a logical relationship to simulate the growth and yield of forest trees or stands. (Kariuki, 2005; Vanclay and Skovsgaard, 1997; Latif et al. 1995 and 1997). Vanclay, J.K. (1994) discussed tables and models: Techniques for predicting stand dynamics are collectively referred to as growth and yield models. The general usage of the term refers to a system of equations that can predict the growth and yield of a forest stand under a variety of conditions. So a growth model can consist of a set of mathematical equations, the numerical values implanted in those equations, the logic necessary to connect those equations in a meaningful way. Forest growth models attempt to quantify the growth of a forest and are commonly used for two main purposes: (i) to predict the future state of a forest and the nature of the harvests from that forest (ii) to consider alternative cultivation practices (Vanclay, J.K., 1994; Latif and Islam, 2001 and Islam, 2018). Models can also invent other uses, such as in education, in the transmission of information, etc. Depending on the purpose of the model, the researcher may choose to emphasize physiological detail or statistical efficiency, but generally aims for both biological and statistical accuracy (Vanclay and Skovsgaard, 1997; Latif and Islam, 2014). In Bangladesh, most researchers developed a growth and yield model using the site index leading equation method and the difference equation method for different tree species. They developed a growth and yield model by establishing PSPs and TSPs for different tree species (Latif and Islam, 2014; Latif et al. 1995 and 1997).

Many forest management decisions depend on the growth and yield of the forest stand. The yield estimate provides information about a specific forest stand at a specific age. This allows decision makers to formulate forest regulation activities and schedules for timber utilization (Vanclay, 1994; Latif and Islam, 2001 and Islam, 2018). In addition, information is needed to evaluate the alternative to economical management of the forest: determining the appropriate rotational age of the forest (Latif, M.A. and Del Castillo, 1991). The growth and yield information can also be used as basic information sources to determine the forest stand performance. Therefore, the prediction of growth and yield serves as a direct input to the other components of the system, especially in the plantations in Bangladesh. The aim of this study is to develop a mathematical model for growth and yield estimation of Akashmoni (*Acacia auriculiformis*) plantations in Bangladesh.

Akashmoni (*Acacia auriculiformis*) is a fast-growing, medium-sized, heavily branched, evergreen tree with a short, forked trunk, belonging to the Leguminnosae family (Das and Alam, 2001 and Latif and Islam, 2004). *A. auriculiformis* occurs naturally in Australia, Papua New Guinea and Indonesia (Das and Alam, 2001). It is an exotic species mainly planted in patches of forest, agroforestry and strip plantations in Bangladesh. It has been cultivated as an exotic species in Asia, Africa and South America for more than 75 years and is increasingly being used for reforestation in new areas (Das, 1986). The species was first introduced by Tea Planter in Bangladesh 45 to 50 years ago (Das, 1986). A few years after the introduction of A. auriculiformis in tea, some parts of woodland and roadsides were planted with the species. It has been planted on a commercial scale in forest plantations nationwide since 1980. Nowadays it is widely planted by Bangladesh Forest Service and private planters.

The growth and yield as well as the determination of the optimal harvest age of the species have not yet been systematically determined. Growth and yield tables for young plantations were prepared and published by Newaz and Kamaluddin (2006). However, these tables are not able to provide accurate growth and yield for all ages of Akashmoni plantations in Bangladesh. However, this information is necessary for the scientific management of the plantations. Growth information of this type is insufficient and cannot be used to develop an age-growth equation. Therefore, the present study has been completed to generate scientific data for predicted growth and yield of Akashmoni (*A. auriculiformis*) based on site indices.

Materials and Methods

Study area

The Forest Department of Bangladesh has taken an initiative to increase and commercialize Akasmoni plantation in the country considering the timber value and construction works. They cultivated huge Akashmoni tree species under forestry sector project in many potential places in Chattogram and Cox's Bazar with spacing 1.8 m × 1.8 m in general. The study was conducted in the remnant the existence Akashmoni plantation in several forest beat of these forest areas (Fig. 1). The Permanent Sample Plots (PSPs) and Temporary Sample Plots (TSP) were taken from the plantations raised by Bangladesh Forest department.

Data for Growth Models

Data have been collected though establishment of PSPs and TSPs from available Akashmoni plantations for development of growth and yield prediction models. For each age classes the plantations were selected at random and then five Permanent Sample Plots (PSP) from each plantation were selected for measurements. Data have been collected from PSPs consecutive seven year. Circular and rectangular plots were taken of area 0.02 hectare each. More than 28 PSPs were established in studied areas for the study (Table

1). All the trees in a plot were marked for diameter measurement at breast height (*Dbh*) (1.3 m above from ground) with red paint and numbered. *Dbh* and total height of all the trees in the plot were measured by diameter tapes and Haga altimeter respectively for successive 7 years.

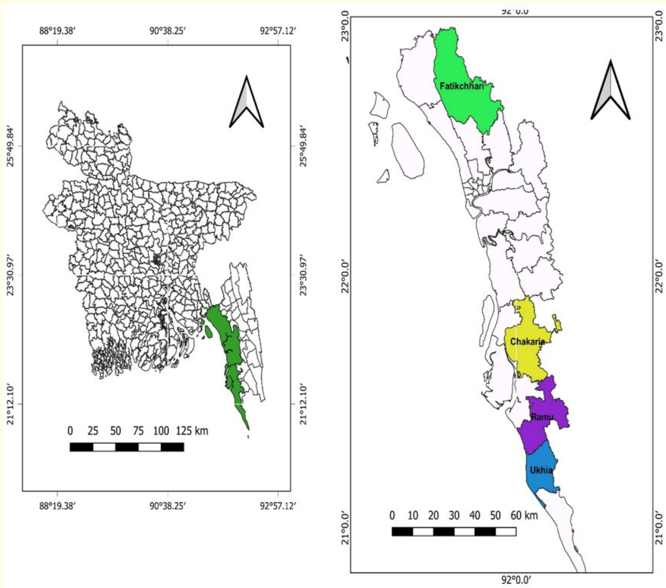

Figure 1: Map of the study area.

Year of Plantation	*PSPs*	*TSPs*	*Total*
2002		8	8
2003	5 (7) = 35	8	43
2004	5 (7) = 35	12	47
2005	5 (7) = 35	12	47
2006	5 (7) = 35	14	49
2007	4 (7) = 28	12	40
2008	4 (7) = 28	12	40
2009		8	8
Total	28 (7 = (196)	86	282

Table 1: Distribution of Sample plots by year of plantations.

The number of permanent sample plots was not enough to predict the growth and yield of the species. Therefore, TSPs were laid out in the available existing plantations of studied areas in Bangladesh. More than 86 TSPs were laid out for the study (Table 1). Ranges with plantations having maximum age ranges were selected. From each plantation at least eight plots were selected at random. The plots were rectangular or circular of 0.02 hectare each. The diameters at breast height (*Dbh*) and total height of all trees in a plot were measured with same procedure of PSPs. The heights of the tallest two trees (100 trees per hectare) per plot were measured by height measuring instrument as dominant height from both PSPs and TSPs. The heights of other trees were estimated by comparing the heights of the trees measured. The Dbh and height of all trees in plots have been entered into the computer for analyses.

Values in the parentheses give the total plots by re-measurement of each plot with successive seven years.

Data collation

For statistical processing, information were derived for mean stand *Dbh*, mean dominant height (*H*), mean stand height (*Mht*), basal area ha^{-1} ($Baha^{-1}$), total volume ($V_t ha^{-1}$) and site index. Average numbers of stem ha^{-1} (Nha^{-1}) at each age group were also determined. The volume of the individual tree was estimated by using the volume equation for the species developed by Latif and Islam (2004) of the form:

$$V_t = -0.0568523 + 0.000019628 \times G^2 + 0.00554848 \times \mathrm{H} + 0.00000153866 \times \mathrm{G} \times \mathrm{H}$$

$$R^2 = 0.97 \text{ and } RSE = 0.150$$

The biomass of the individual tree was estimated by using the biomass allometric model for the species developed by Hossain et al (2020) of the form:

$$\ln(TAGB) = -2.459 + 1.869 \times \ln(\mathrm{D}) + 0.800 \times \ln(\mathrm{H})$$

$$R^2 = 0.986 \text{ and } RSE = 0.123$$

The following models were tested for selection of the best-suited site index guide model:

The site index models in the form:

1. Power model

$$\mathrm{H} = \mathrm{b_0 A^{b_1}}$$

2. Schumacher models, modified by adding a constant

$$\mathrm{H} = \mathrm{b_0 exp\,(b_1 A^{-k})} \qquad 0.2 \le k \le 2.0$$

3. Chapman-Richards model

$$\mathrm{H} = \mathrm{b_2(1 - exp(-b_1 A))^{b_3}}$$

4. Lars strand equation

$$\mathrm{H} = \frac{\mathrm{A}}{(\mathrm{b_0 + b_1 A})^3}$$

Where, b_0 is the intercept, b1 is the slope, b_2 is the asymptote, b3 is the inflection point.

H is the mean dominant height in meters of 100 dominant (tallest) trees ha^{-1} and A is the age of the plantation in years.

Among the above mentioned models, the best suited model were selected subject to the fulfillment of the statistical and biological requirements. The elaboration of Site Index Curves (*SIC*) for studied tree species followed the "difference equation method" procedure as suggested by Clutter at al. (1983).

For determination of the best suited growth and yield models, the site index guide equation was developed first. This was followed by derivation of stand mean diameter at breast height (*Dbh*), stand mean height (*Mht*), stand basal area ha^{-1} ($Ba\ ha^{-1}$), stand volume ha^{-1} ($Vt\ ha^{-1}$) and stand above ground biomass ha^{-1} ($Biom\ ha^{-1}$) yield models. The independent variables of the stand yield prediction models were age and site index and the dependent variable was *Dbh*, *Mht*, $Ba\ ha^{-1}$, $V_t\ ha^{-1}$ and $Biom\ ha^{-1}$. One model to estimate the numbers of trees per hectare at different ages were also derived. Step-wise and all probable combinations of the independent variables regression methods were used to select the best suited models subject to the satisfaction of the statistical and biological requirements. Different transformations of the variables either in the form of natural logarithm (ln), reciprocal or combining two variables in the transformed or in the original forms or combinations along with the original variables were used for regression analyses. All possible regressions were worked out by taking ln as dependent variable. Independent variables in the form of 1/ S, ln(S), 1/ ln(S) for site index and 1/A, ln(A) and S/A for age were used. Two-stage least squares method was used to choose desired equation out of the different combinations. In this way, equations for stand mean height, stand *Dbh*, stand basal area ha^{-1}, stand volume ha^{-1} and stand biomass ha^{-1} were derived. The stand variables presented in the table 2.

Variables	*Mean*	*SE of mean*	*SD*	*Minimum*	*Maximum*
Age (years)	10.6	0.2	2.9	4.4	16.6
Site index (m)	15.9	0.3	4.3	9.1	21.3
Stemha^{-1} (N)	1507	31	523	750	2900
Dbh (cm)	14.7	0.2	3.7	5.3	20.8
Mht(m)	14.1	0.2	2.8	6.0	19.5
Domht (m)	17.2	0.2	3.3	8.0	23.5
Ba ha^{-1} (m^2)	23.9	0.4	7.5	6.3	36.1
V_t ha^{-1} (m^3)	88.7	1.9	31.5	10.3	129.5
Biomass ha^{-1}(ton)	149.4	3.5	59.2	27.3	253.3

Table 2: An indicative distribution of different variables for growth and yield models of Akashmoni (A. auriculiformis) planted in Bangladesh.

Model performance criteria

The selection of appropriate criteria to assess the model performance is a critical consideration. There is no single criterion for selecting the best regression model from among a number of models (Aertsen et al., 2010). Using multiple measurements of performance instead of single measurements is a common and more objective approach (Aertsen et al., 2010).

The most commonly used criteria to evaluate the model performance are the coefficient of determination (R^2). The R-squared (R^2) statistic measures the success of the regression in predicting the values of the dependent variable within the sample. In standard settings, may be interpreted as the fraction of the variance of the dependent variable explained by the independent variables. The statistic will very closed to one the regression fits perfectly. The R-squared (R^2) measured as:

$$R^2 = 1 - \frac{\sum_i (y_i - \hat{y}_i)^2}{\sum_i (\hat{y}_i - \bar{y}_i)^2}$$

The root mean square error (*RMSE*) is a well-accepted goodness-of-fit indicator describing the difference in observed and predicted values in the appropriate units with lowest value (Aertsen et al., 2010). *RMSE* is defined as follows:

$$RMSE = \sqrt{\frac{\sum_i (y_i - \hat{y}_i)^2}{N}}$$

where, where y_i and $\hat{y}_i$ are the original data values and modeled (predicted) values respectively and $\bar{y}$ mean of original data. N is the number of pairs of values.

The Akaike Information Criterion (*AIC*) is considered as one of the most reliable criteria for comparing models with a range of parameters (Sharma, 2009 and Hossain et al., 2020). The model with the smallest *AIC* is considered optimal. For the least squares fit, it is calculated as follows (Aertsen et al., 2010):

$$AIC = -2(\text{log-likelihood}) + 2K$$

Where, K is the number of model parameters (the number of variables in the model plus the intercept). Log-likelihood is a measure of model fit. The higher the number, the better the fit. This is usually obtained from statistical output.

Model Validation

Statistical validation

Statistical validation was the first step done in validating the models. It included the analysis of variance minimum residual mean square, the highest coefficient of determination (R^2) with lowest *RMSE*.

Independent test

Validation of the chosen models of stand height for Akashmoni was done by using data from 30 separate sample plots. This was done by comparing the estimated and observed values, applying the chi-sq`uare test of goodness of fit, paired t-test and percent absolute deviation (%*AD*). This was also compared with 45 degree line test by plotting the observed values and the predicated value in the graph.

Biological principle testing

For biological principle testing, predicted Stand mean height, stand *Dbh*, stand basal area ha^{-1}, total volume yield ha^{-1} and above ground biomass yield ha^{-1} derived from the chosen models were plotted against age for different site indices. The yield curves should be of sigmoid shape and asymptotic to the carrying capacity of the site (Latif, et al., 1997 and Islam, et al. 2018).

Data analysis

Collected data were organized and screened (removing the outliers) for analysis. Descriptive statistical analysis was further carried out in order to summarize the data. All analysis carried out were conducted using MS Excel 2013, SPSS 17 Inc and E Views (Quantitative Micro Software, LLC) statistical package version 9.

Result

Development of site index guide equation

The growth and yield prediction models of the Akashmoni (*Acacia auriculiformis*) have been developed by site index guide equation method. The all growth parameters have been measured from total of 282 individual permanent and temporary sample plots (table 1) in this study. The scatter plot of the individual mean dominant height and age of the species grown in the plantations in Bangladesh is presented by figure 2. It is also scatter relationship between dependent variable (dominant height) and independent variables (age) using the actual field data before model fitting. The figure shows the mean dominant height of a stand monotonically increase as the age of the stand increase that indicates high correlation between these two variables.

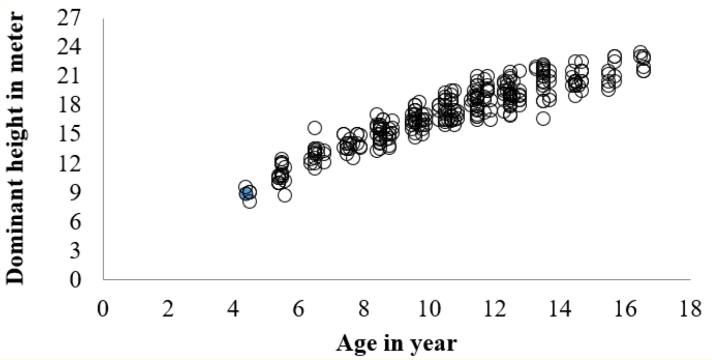

Figure 2: The scatter plot of the individual mean dominant height with independent variable age of Akashmoni (A. auriculiformis).

The Schumacher's model (Model 2) to develop site index guide equation was found best for Akashmoni in the plantations in Bangladesh. The specific form of the model is given by.

$$ln(Domht)=4.967357-4.283731\times A^{-0.3};\ R^2 = 0.92,\ RMSE = 0.064$$

$$\text{and } AIC = -2.77$$

The site index guide curve is given in figure 3.

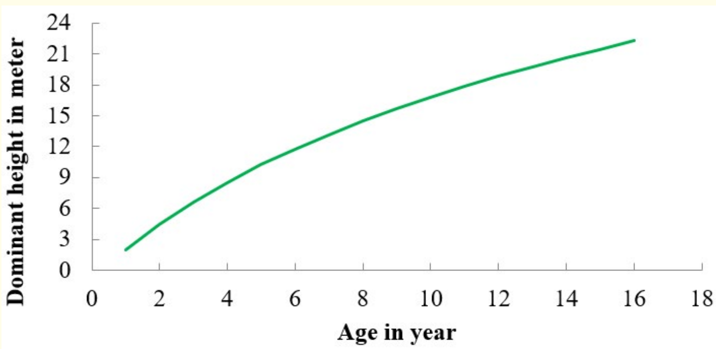

Figure 3: Site index guide equation for Akashmoni (A. auriculiformis) plantations in Bangladesh.

To obtain the site index for each plot, a reference age of 12 years used and the specific equation is given below:

$$ln(SI) = -2.032674 + ln(Domht) + 4.283731 \times A^{-0.3}$$

Where, SI = site index of an individual sample plots at the base age 12 years and *Domht* = dominant height in meter.

The dominant height for different site indices at different age may be estimated by using the above equation. The dominant height growth curves at different site indices are shown in figure 4.

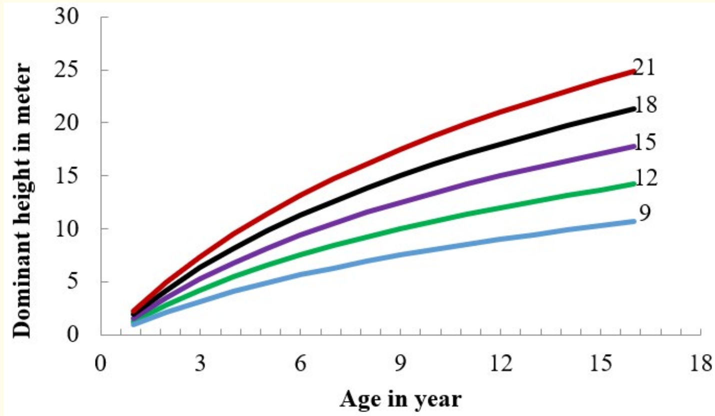

Figure 4: The dominant height growth curves at different site indices for Akashmoni (A. auriculiformis) plantations in Bangladesh.

The selected prediction equation of stem ha^{-1} (Nha^{-1}), stand mean height (*Mht*), stand diameter at breast height (*Dbh*), stand density or stand basal area (*Baha^{-1}*) ha^{-1}, stand volume ($V_t ha^{-1}$) ha^{-1} and stand biomass (*Biomha^{-1}* ha^{-1} are stated in table 3 below along with the corresponding coefficient of determination and root square mean error.

Equation	R^2	*SE*	*AIC*
$\ln(Nha^{-1}) = 9.624812 - 1.016892 \times \ln(A)$	0.88	0.115	-1.474
$\ln(Dbh) = 1.509138 - \frac{4.006475}{A^{0.4}} + 0.990822 \times \ln(SI)$	0.98	0.004	-8.389
$\ln(Mht) = 0.685711 - \frac{2.592535}{A^{0.5}} + 1.000965 \times \ln(SI)$	0.83	0.093	-1.884
$\ln(Baha^{-1}) = 0.806195 - \frac{17.500116}{A^{1.8}} + 0.957218 \times \ln(SI)$	0.90	0.096	-1.828
$\ln(V_t ha^{-1}) = 3.093775 - \frac{52.173172}{A^{2}} + 0.678476 \times \ln(SI)$	0.87	0.148	-0.946
$\ln(Biomha^{-1}) = 2.376888 - \frac{14.674297}{A^{1.4}} + 1.152996 \times \ln(SI)$	0.93	0.110	-1.568

Table 3: Predicted growth and yield models for Akashmoni (A. auriculiformis) plantations in Bangladesh.

Statistical validation and biological principle testing
Independent test

The computed chi-square, t-value, absolute deviation percent (%AD) and slope for number of tree per hectare mean height, diameter at breast height, basal area, volume yields and biomass yields are given in table 4. Graphs comparing the observed values and the predicted values were plotted in the graph paper for the 45 degree line test. It was observed that the models tend to make an angle of 45 degree with the axes meaning there is no significant difference between actual and predicted values.

Variables	*Chi*	*t*	*%AD*	*Slope°*
Nha^{-1} (N)	14.5	1.36	0.3	42.1
Dbh (cm)	4.3	0.45	1.6	44.1
Mht (m)	4.9	0.52	2.0	42.8
$Baha^{-1}$(m^2)	11.7	0.69	0.7	43.8
$V_t ha^{-1}$(m^3)	10.9	0.42	1.4	44.1
$Biomha^{-1}$(ton)	9.5	0.49	0.2	44.7

Table 4: Result of independent test for developed growth and yield models.

Discussion

The performance measures for 4 generalized height growth functions, the site index governing equation, have been developed. Considerable differences were observed between the predictive abilities of the generalized dominant height-age models. Models with the lowest RMSE and AIC values (closest to zero) and the R^2 closest to one have the best performance (Ahmadi et al. 2016, Islam, 2018). The highest R2 is achieved on the Schumacher model (0.92), with the lowest RMSE (0.064) and AIC values (-2.77) flowing from others. The Schumacher models explained at least 92% of the total variation in tree-dominant heights. Model development was performed, all partial regression coefficients were statistically significant at 0.01%. The selected site index guidance equation met all statistical criteria. The predicted value was plotted against age for various site indices. The growth curves were sigmoid (Figure 1).

The growth and yield models for Akashmoni (*Acacia auriculiformis*) in Bangladesh plantation were constructed based on the site index using the simultaneous equation method. The functions are derived from a mathematical growth model, which assumes that the effects of different growth factors interact in a multiplicative manner. Predicting growth and yield models that were developed consisted of six equations: stand stocking equation, stand DBH equation, stand average height equation, stand basal area (density) equation, stand total volume yield equation and stand total biomass yield equation. The highly significant regression coefficients of the projected models for canopy thrust, canopy diameter at breast height, mean canopy height, canopy basal area, volume yield and biomass yield are 0.88, 0.98, 0.83, 0.90, 0.87 and 0.93, respectively (Table 3). These show that the predicted ha^{-1} of the strain (stocking) correlates strongly with the standing age of the independent variable (A). Stand diameter at breast height, mean stand height, stand area ha^{-1}, stand volume yield ha^{-1} and stand biomass yield ha^{-1} correlate strongly with the independent variables age (A) and site index (SI). These also indicate that the models for canopy thrust, canopy diameter at breast height, mean canopy height, canopy footprint, volume yield and canopy biomass explain 88%, 98%, 83%, 90%, 87% and 93%, respectively, of the total variation at significant levels of. Standard error of 11 stem numbers ha^{-1}, 0.004 centimeter Dbh per tree, 0.09 meter mean stand height per tree, 0.096 square meter stand area ha^{-1}, 0.148 cubic meter stand volume result in ha^{-1} and 0.11 tons stand biomass yield ha^{-1} for Akashmoni (*A. auriculiformis*) showed a relatively low value, indicating the best fit of the models (Table 3). The indicative prediction curves given in figure 5.

The selected models met all statistical criteria. The predicted values were plotted against age for various site indices (Figure 5). The curves found confirm the ideal properties of a biological yield curve. The yield curves were sigmoid. The yield curves also showed that higher yields can be expected for a given stand age in better locations. The calculated chi-square and T values were smaller than the table values. These imply that there is no significant difference between the actual values from the 30 test sample plots and the corresponding expected values as predicted by the models. Therefore, the selected models confirm the data set.

This study provides details on growth and yield models of Akashmoni (*A. auriculiformis*) plantations in Bangladesh. The growth and yield models will predict tree stand number (spike) ha^{-1}, mean stand height, dominant stand height, stand diameter at breast height, stand base area (density) ha^{-1}, stand volume ha^{-1} and stand biomass ha^{-1} at different locations. Forest users can easily obtain values from the tables generated by the predicted models of these parameters at will, rather than calculating them for general use. Knowing the age and location indices of a given population of Akashmoni (*A. auriculiformis*), users can easily and confidently estimate the growth and yield variables using the models presented in this study. The predictive models can be used for trees ranging in age from 4.4 to 16.6 years and site indices from 9 to 21 meters based on a base age of 12 years. Extrapolation over this data range is not recommended.

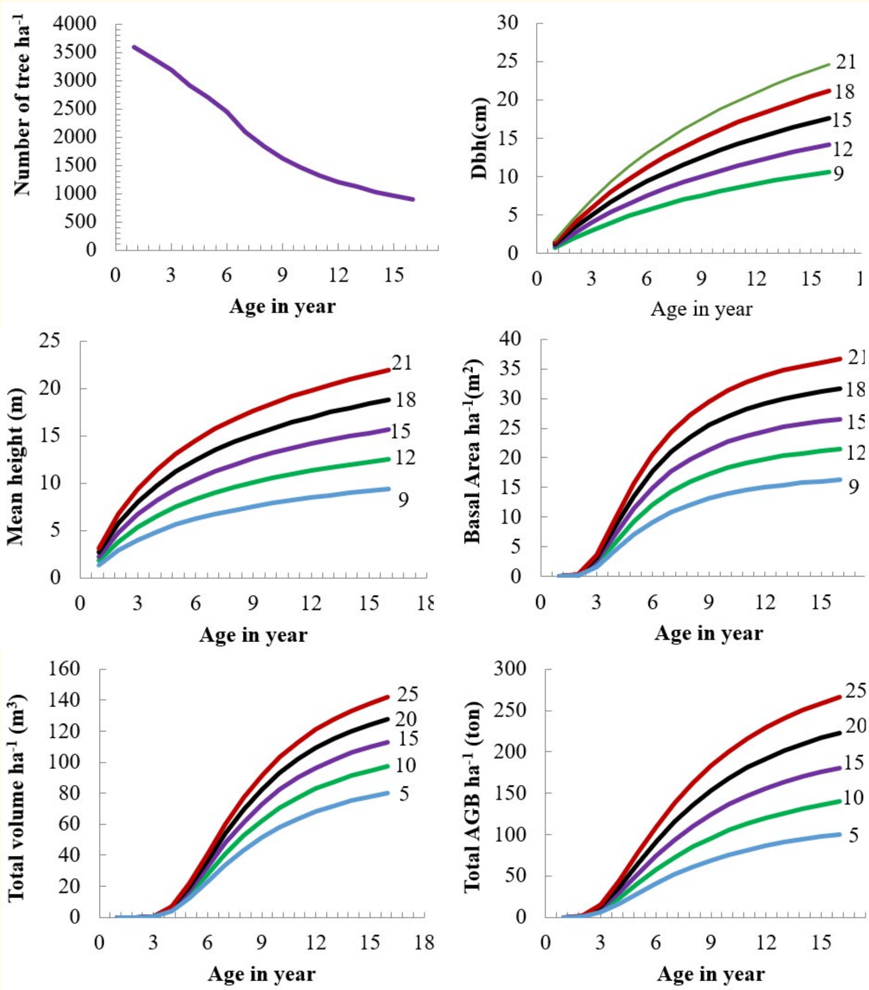

Figure 5: Predicted growth and yield curves of Akashmoni (A. auriculiformis) plantations in Bangladesh.

The author believes that the sample plots covering the range of site variation and stand history for specific forest types or plantation types are necessary for the development of a standard model. However, this could not be achieved in this study due to the time limitations intended for the study and other necessary factors. Developing growth and revenue models after PSPs are established requires more than ten years of consecutive data sets. In addition, the Akashmoni plantation (*A. auriculiformis*) was so widely scattered in the country that it was not possible to equally distinguish bad sites, average sites, good sites, low-density stands, medium-density stands, high-density stands, old deforested stand, is mid-rotation or mid-cutting cycle, and is in the rotation age or end-of-cutting cycle required for development of an ideal model. Also, not all age classes of the Akashmoni (*A. auriculiformis*) were present in the study area. Apart from these, no conventional thinning was carried out in the plantations studied. As a result, some anomalies were found in the analysis of the collected data. The models can be improved by using data collected from a wide range of stocking variations (number of stems per unit area) to examine independent variables to get a more accurate estimate. In this study, growth and models were developed for Akashmoni (*A. auriculiformis*) planted in Bangladesh by site index guide equation. All growth and models contribute significantly to improving our knowledge Akashmoni tree growth in Bangladesh.

Conclusion

The main aim of this study was to measure the growth and yield of Akashmoni (*Acacia auriculiformis*) with different selective appropriate methods for their possible application in growth and yield simulators and basic calculations of forest inventories in Bangladesh. Therefore, the model predictors used are variables that are typically measured in forest inventories. The inventory data collected during the field inventory were suitable for building these models. In this study, the total volume of the Akashmoni tree was predicted by the model developed by Latif and Islam (2004) and the biomass was estimated using a model by Hossain et al. predicted. (2020), was taken as the absolute true value for individual tree volume and biomass. Growth and yield prediction models were developed in the present study to support sustainable management of the Akashmoni forest in Bangladesh. Most of the statistical and biological tests of the presented models showed reasonable prediction accuracies. The models in this study performed well in independent test data and were consistent with forest growth theory. In Bangladesh, the growth models can be used in forest planning calculations to assess the site quality and to estimate the yield of a stand at a specific point in time.

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