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Growth and Yield Prediction Models for Hybrid Acacia (*A. auriculiformis* X *A. mangium*) Grown in the Plantations of Bangladesh

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Abstract: The present study aimed at development of growth and yield prediction models for hybrid acacia using simultaneous equation method. Models were selected for the species to estimate the stand height, stand dominant height, stand diameter, stand basal area per hectare and total volume yield per hectare. Paired t-test, 45-degree line test, percent absolute deviation and biological principle of stand development were used for the validation of chosen models. The results suggest that the models derived were statistically and biologically acceptable and could be satisfactorily used for stands of Hybrid *Acacia* of ages 4-7 years based on a base age of 6 years in the central region of Bangladesh.

Key words: Growth, yield, hybrid acacia, central region, Bangladesh

INTRODUCTION

Acacia auriculiformis and *Acacia mangium* are two fast-growing tree species belonging to the family *Leguminosae*. *Acacia auriculiformis* occurs naturally in Australia, Papua New Guinea and Indonesia. In Australia, it is found in the north of the Northern Territory (11-14° S and 130-135° E), Cap York Peninsula, Queensland and on islands in Torres Strait (10-16° S and 142-145° E). In Papua New Guinea, the main occurrences are in Western Province extending from 9° S, 141° E to 90° S, 143° E. In Indonesia it is known to occur in Irian Jaya and in the Kai Island. It is perhaps better known outside its natural range of distribution as a most adaptable species for all kinds of tree planting programs in tropical humid and sub-humid low land regions. It has been cultivated as an exotic in Asia, Africa and South America for more than half a century and is being increasingly used for reforestation in new areas[1]. The species was first imported in Bangladesh by Tea Planters 25–30 years ago[2]. A few years back after the introduction of *Acacia auriculiformis* in tea, some parts of forest areas and roadsides were planted with the species. Since 1980 it is being planted at operational scale in the forest plantations throughout the country[3]. In 1983–88, provenance trials of seven provenances (CSIRO 13191, 13499, 13684, 13685, 15477, 15483 and 15697) of the species were established in different parts of the country and the growth have been found better compared to trees from local seeds[4]. In 1997 another provenance (CSIRO 19305) was tried and found better in performances.

Acacia mangium occurs naturally in the humid tropical low lands of Queensland, Northern Australia, Papua New Guinea and Eastern Indonesia[5]. It can be planted in hard compact soils, Savannah areas, dry ridge tops and slopes of hills, moist hill foots, infertile dry soils, etc. The northern limit of the species is 0°50′ S in Irian Jaya and the southern limit is 18.5° S in Queensland, Australia[3]. On poor sites in Sabah, Malaysia, *Acacia mangium* notably outperformed the other species tested. *A. mangium* has grown vigorously on disturbed or burned sites, on degraded oxisols (laterite) underlain with volcanic rock, on soils so worn out that shifting cultivation had been abandoned and on hill slopes infested with weeds such as *Imperata cylindrica* and *Eupatorium* sp.[6]. Midgley and Vivekanandan[7] reported that *A. mangium* has the ability to tolerate extended drought as proven by agroforestry trials in Sri Lanka. Haishui and Zengjiang[8] stated that large scale plantations of the species are being established successfully in Southern China, below latitude 23.5° N having annual mean temperature 20° C (max. 38° C, min 5° C); annual rainfall 1500 mm mainly occurring from March to July on the mainland and June to October on Hainan Island. Pinyopusarerk[9] stated that *A. mangium* grows well under the latitudinal range of 01–18° S, attitudinal range of 0–800 m, rainfall range of 1000–3000 mm in sandy-loam soil having acid-alkaline reaction. In Bangladesh *Acacia mangium* was first tried by the Bangladesh Forest Research Institute (BFRI) in 1979 and was shown that the species could be profitably grown in the edaphic and climatic conditions of the country[3]. In 1983 comprehensive provenance testing of the species was done in a trial of 23 provenances and four provenances were found suitable for Bangladesh[10].

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In 1988 a trial of another 16 provenances was established at Keochia, Chittagong. Forest Department used seeds of five Queensland provenances in raising plantations for fuelwood and poles in its Community Forestry Project in NW Bangladesh in 1983–1987[4]

Acacia auriculiformis and *Acacia mangium* are predominantly out-crossing and naturally crossed hybrid trees are found within natural range of the species as well as outside their natural range[11]. The hybrid acacias show promising growth. Naturally-crossed acacia hybrids in Sabah were first noted in the late 1970[12]. The acacia hybrid possessed a number of attractive characteristics much sought in tree improvement. Generally it has better growth, straight bole, less persistent branching and more cylindrical stem than its parents[13]. Natural hybrids have been reported in Sabah, Papua New Guinea, Malaysia and in other localities where *A. auriculiformis* and *A. mangium* grow in close proximity, with overlapping flowering times[14]. In Bangladesh hybrid acacias are available sporadically in the plantations of *A. auriculiformis* and *A. mangium* raised through out the country in the form of woodlot plantations, agroforestry plantations, roadside/strip plantations, embankment plantations and reforestation in the denuded hills. As the hybrids are found growing naturally in most of the *A. auriculiformis* and *A. mangium* plantations, the climatic and site requirements of the species might be similar to that for the parental species.

Though hybrid acacias, available in the plantations of *A. auriculiformis* and *A. mangium* of different ages, are showing outstanding performances, information about its performances in variety of sites and climates are still limited. Their growth and yields are known in general terms, instead of scientific and systematic. But systematic information is necessary before initiating massive plantation programs with hybrid acacias. Therefore, to ensure scientific management of the plantations, the growth and yield tables for the species were felt necessary and the present models/tables have been prepared based on site indices.

MATERIALS AND METHODS

The study has been conducted in the woodlot plantations of Tangail Forest Division, where plantations of maximum age classes (3, 4, 5, 6, 7, 9 years) were available. Plantations of all age classes were visited and available hybrid acacias were identified. Hybrid acacias were found sporadically available in the plantations of 4, 6 and 7 years of ages. For the study, the whole population of hybrid acacias comprising a total of 317 individuals was measured. Heights were measured to the nearest 0.25 m by Spiegel Relaskop and diameter at breast height (dbh) were measured to the nearest 0.1 cm by diameter tape. Heights of the tallest two trees from each stand were measured for estimation of the dominant height. Circular plots having an area of 0.02 ha (radius r = 7.98 m) were taken encircling the hybrid/hybrids and the total number of individuals including *A. auriculiformis* and *A. mangium* within the circle were counted for the estimation of stand density. The spacings of the plantations were 1.6x1.6, 1.8x1.8 and 2.0x2.0 m.

Data Collection: Information were derived for stand age (A), average stand height (mht), average dominant height (H), dbh of the mean tree (D), basal area per hectare (BA ha^{-1}), total volume yield per hectare (Vt ha^{-1}), spacing of the trees and site index (S) for statistical analysis. The volume of individual tree was estimated using the volume equation $V = a + bD^2 + cDH + dD^2H$, derived for hybrid acacia by Rahman and Kamaluddin[15].

Following models were tested for the selection of the best-suited site index guide equation:

$$\log (H) = b_0 + b_1 \log (A) \qquad (1)$$
$$\log (H) = b_0 + b_1/A^k \quad 0.2 = K = 2.0 \qquad (2)$$

where: b_0 = Intercept,
b_1 = Slope,
H = Total height of 100 dominant and codominant trees per hectare,
A = Age of the plantation in years.

The two models were evaluated based on the statistical and biological requirements and the best suited one between the two was selected. A base or reference age of six years was used to determine the site index of individual sample plots.

To determine the acceptable yield models, site index model was derived first. Then models were derived for stand diameter (D), stand height (mht), stand basal area per hectare (BA ha^{-1}) and total volume yield per hectare (Vt ha^{-1}). The independent variables of the stand yield prediction models were age and site index and the dependent variable was the natural logarithm (LN) of stand yield per hectare. Step-wise and all probable combinations of independent variables regression methods were used to select the best suited models subject to the fulfillment of the statistical and biological requirements. Different transformations of the variables either in the form of 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. Stepwise regression analysis was done to derive the best-suited prediction models. All possible regressions were worked out by taking LN as dependent variable. Independent variables in the form of 1/S, log (S), 1/log (S) for site index and 1/A, log (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 height, stand dbh, stand basal area per hectare and volume per hectare were derived.

Model validation

Statistical validation: Statistical validation was done first in validating the derived models through the analysis of variance, the highest coefficient of determination (R^2), the highest adjusted R^2 and the minimum standard error.

Biological principle testing: For biological principle testing, predicted stand height, stand dbh, stand basal area per hectare and total volume yield per hectare derived from the chosen models were plotted against age for different site indices.

Independent test: Using data from 9 independent sample units validation of the chosen models was done. For this the actual values of these units were collectively compared with the corresponding values predicted by the chosen models. The comparisons were made with the help of pared t-test and absolute deviation percent. These were also compared with 45° line test. The observed values and the predicted values were plotted to see the trend of the slope of expected curves. If the expected curves tend to make an angle of 45° with the axes, this means that there is no significant difference between the actual values and the predicted values. The null hypothesis was that there was no significant difference between outputs from the sampled units specified for data validation and the corresponding expected values from the models.

RESULTS AND DISCUSSION

A site index equation is usually considered well fitted when coefficient of determination (R^2) and variance ratio are high and standard error is low. Site index model 2 showed higher values for the coefficient of determination (R^2) and variance ratio and a lower value for standard error than the site index model 1. Hence, site index model 2 was chosen for this study. As such, the specific form of the equation is given below:

$$\log(H) = 3.495 - 14.63 / A^{1.2},\ R^2 = 0.84$$

The logistic model for the chosen site index guide equation was among many alternative models based on constant k. A reference age of 6 years was used to obtain the site index for each plot and the specific equation for the species is given as:

$$\log(H) = 1.704 + \log(S) - 14.63 / A^{1.2}$$

Where, S = site index of an individual sample unit at the base age of six years.

The chosen stand height (mht), stand diameter (D), stand basal area per hectare (BA ha^{-1}) and total volume yield per hectare (Vt ha^{-1}) models are stated below along with their corresponding coefficients of determinations:

Height equation:
$$\log(mht) = 1.867 + 0.62 * \log(S) - 5.846/A^{1.2},\ R^2 = 0.897$$

Diameter equation:
$$\log(D) = 3.64 - 6.267/A + 0.235 * S/A,\ R^2 = 0.923$$

Stand basal area equation:
$$\log(BA\ ha^{-1}) = 4.634 - 14.63/A + 0.73 * S/A,\ R^2 = 0.790$$

Total volume yield equation:
$$\log(Vt\ ha^{-1}) = 6.627 - 17.391/A + 0.734 * S/A,\ R^2 = 0.717$$

The stand height, stand diameter, stand basal area and volume yield models explain 89.7, 92.3, 79.0 and 71.7% of the total variation, respectively.

Statistical validation and biological principle testing: In statistical testing of the developed models, the selected site index guide equation produced highest coefficient of determination (R^2), highly significant values of F and low standard errors, i.e. the selected models satisfied all the statistical criteria. These indicate statistical acceptability of the selected models. The yield curves were found sigmoid, which reasonably satisfied the biological principles of growth and development. The yield curves shifted upward with increasing site quality and the yield is monotonic increasing with time or age of the stand. All these confirmed the ideal attributes of a biological yield curve.

Independent test: The computed t-values for all the estimates were less than the tabular t-values ($t_{0.95,8}$=2.306). These imply that there were no significant differences between the observed and the predicted values. Thus the selected models might be acceptable.

45-degree line test: The observed values and the predicted values yielded slops of more or less 45 degrees.

Table 1: Dominant height (m), Stand mean height (m) and Stand diameter (cm) for Hybrid Acacia in the plantations of the central region of Bangladesh

Age in years	Dominant height (m) Site index (m) 6.0	9.0	12.0	15.0	18.0	Stand mean height (m) Site index (m) 6.0	9.0	12.0	15.0	18.0	Stand diameter (cm) Site index (m) 6.0	9.0	12.0	15.0	18.0
1.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.3	0.6	1.2	2.5	5.0
2.0	0.1	0.1	0.1	0.1	0.2	1.5	2.0	2.4	2.7	3.0	3.4	4.8	6.8	9.7	13.8
3.0	0.7	1.0	1.3	1.6	2.0	4.1	5.3	6.3	7.3	8.1	7.5	9.5	12.1	15.3	19.3
4.0	2.1	3.1	4.1	5.2	6.2	6.5	8.3	10.0	11.5	12.8	11.3	13.5	16.1	19.2	22.9
5.0	4.0	5.9	7.9	9.9	11.9	8.4	10.8	12.9	14.9	16.6	14.4	16.6	19.1	22.0	25.3
6.0	6.0	9.0	12.0	15.0	18.0	9.9	12.8	15.3	17.6	19.7	17.0	19.1	21.4	24.1	27.1
7.0	8.0	12.0	16.0	20.0	24.0	11.2	14.3	17.1	19.7	22.0	19.0	21.0	23.3	25.7	28.5
8.0	9.9	14.8	19.7	24.7	29.6	12.1	15.6	18.6	21.4	24.0	20.8	22.7	24.8	27.0	29.5
9.0	11.6	17.4	23.1	28.9	34.7	12.9	16.6	19.9	22.8	25.5	22.2	24.0	26.0	28.1	30.4
10.0	13.1	19.7	26.2	32.8	39.3	13.6	17.5	20.9	24.0	26.8	23.4	25.1	27.0	29.0	31.1
11.0	14.5	21.7	29.0	36.2	43.4	14.1	18.2	21.7	25.0	27.9	24.5	26.1	27.8	29.7	31.7
12.0	15.7	23.6	31.4	39.3	47.1	14.6	18.8	22.4	25.8	28.9	25.4	27.0	28.6	30.3	32.1

Table 2: Stand basal area per hectare (m^2ha^{-1}) and total volume yield per hectare (m^3ha^{-1}) for hybrid acacia in the plantations of the central region of Bangladesh

Age in years	Stand basal area per hectare (m^2ha^{-1}) Site index (m) 6.0	9.0	12.0	15.0	18.0	Total volume yield per hectare (m^3ha^{-1}) Site index (m) 6.0	9.0	12.0	15.0	18.0
1.0	0.0	0.0	0.3	2.6	23.6	0.0	0.0	0.1	1.3	11.6
2.0	0.6	1.8	5.5	16.5	49.3	1.1	3.4	10.3	31.1	93.5
3.0	3.4	7.0	14.6	30.3	63.0	10.0	20.7	43.2	90.0	187.5
4.0	7.9	13.8	23.8	41.2	71.2	29.4	50.9	88.3	153.2	265.7
5.0	13.3	20.6	31.9	49.5	76.7	56.2	87.4	135.7	210.8	327.4
6.0	18.7	26.9	38.8	55.9	80.5	86.7	125.1	180.6	260.7	376.3
7.0	23.8	32.6	44.6	61.0	83.4	118.1	161.8	221.6	303.5	415.7
8.0	28.6	37.6	49.5	65.1	85.6	149.0	196.1	258.3	340.1	447.9
9.0	33.0	42.1	53.7	68.5	87.4	178.4	227.8	291.0	371.7	474.7
10.0	37.0	46.0	57.3	71.3	88.8	206.1	256.9	320.1	399.0	497.3
11.0	40.6	49.5	60.4	73.8	90.0	231.9	283.3	346.1	422.8	516.5
12.0	43.8	52.6	63.2	75.8	91.0	255.9	307.4	369.4	443.7	533.1

It can be observed that the models tended to make an angle of 45 degrees with the axes, meaning there is no significant difference between the actual and the predicted values. Absolute deviation percent (AD%) between observed and the predicted values for all the variables were minimum. The models give underestimation of the values within the range of 2.286 to 5.036%. This also confirmed validity of the selected models.

The computed t-values, slope and absolute deviation percent (AD%) for stand mean height (mht), stand dbh, stand basal area per hectare (BA ha^{-1}) and total volume yield per hectare (Vt ha^{-1}) are stated below:

Variable	t-value	Slope°	%AD
mht	0.63	44.15	3.352
dbh	0.16	45.28	2.286
BA ha^{-1}	0.15	41.25	3.007
Vt ha^{-1}	0.40	44.33	5.036

After the confirmation of the validity of the selected models through validity test, stand dominant height, stand mean height, stand diameter, stand basal area per hectare and total volume yield per hectare were estimated and presented in Table 1 and 2. Forest users will readily get values from the result of Table 1 and 2 of stand dominant height, stand mean height, stand diameter, stand basal area per hectare and total volume yield per hectare as desired rather than calculating them for general uses. If the users know the average dominant height of trees of a given stand it will be easy and safe for them to estimate the site index of it by using the dominant height-site index and age relationship model and then to estimate other necessary variables by using the models and/or tables given in this study. The yield prediction models and their uses are recommended for stands of ages 4-7 years within the limitations of the data used in the study. Beyond this range, validation of the models will be necessary.

The models may further be improved by using data collected from a wide range of variations covering poor sites, average sites, good sites, low density stands, stands of average density, high density stands, young or recently logged stands, stands at mid rotation or midway through felling cycle and stands at rotation age or at the end of the felling cycle. Study of more available age classes of hybrid acacia will also be helpful for the development of ideal models.

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