GROWTH AND YIELD TABLES FOR *ACACIA MANGIUM* GROWN IN THE PLANTATIONS IN BANGLADESH

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LATIF, M.A., DAS, S. RAHMAN, M.F. & HABIB, M.A. 1995. Growth and yield tables for *Acacia mangium* grown in the plantations in Bangladesh. *Acacia mangium* has been found suitable for Bangladesh and is included in the plantation programme. Models were selected for the species to estimate the stand dominant height, stand height, stand diameter, stand basal area per hectare, total volume yield per hectare, above ground green biomass yield per hectare and green biomass of the stem and branches per hectare. The yield prediction models derived in the study could be satisfactorily used for mangium plantations of ages 1-9 years and site indices of 8.0 to 20.4 m based on a base age of 6 years.

Keywords: Growth - yield - biomass - *Acacia mangium* - Bangladesh

LATIF, M.A., DAS, S. RAHMAN, M.F. & HABIB, M.A. 1995. Jadual tumbuhan dan hasil untuk *Acacia mangium* yang ditanam di ladang-ladang di Bangladesh. *Acacia mangium* didapati sesuai untuk Bangladesh dan dimasukkan dalam program ladang. Model-model dipilih untuk spesies ini untuk menganggarkan tinggi dirian dominan, tinggi dirian, diameter dirian, luas pangkal dirian sehektar, jumlah hasil isipadu sehektar, hasil biojisim hijau atas tanah sehektar dan biojisim hijau batang dan dahan sehektar. Ramalan hasil untuk model-model yang diperolehi dari kajian ini boleh digunakan dengan memuaskan untuk ladang mangium yang berumur 1 hingga 9 tahun dan indeks tapak sebanyak 8.0 ke 20.4 m berdasarkan umur asas 6 tahun.

Introduction

Acacia mangium Willd. (mangium) is a promising fast-growing multipurpose tree species of the family *Leguminosae*. It is indigenous to Northern Australia, Papua New Guinea and Eastern Indonesia (Anonymous 1980). The species was first tried in Bangladesh in 1979 and the initial performance was satisfactory. Subsequently, a provenance trial of 23 provenances was established in 1983 and provenances of West of Morehead, Oriomo River of Papua New Guinea, Abergowrie SF, Hawkins creek RD, and Parish of Leach Queensland were found suitable for Bangladesh (Zashimuddin *et al.* 1983). Since then the species is being planted in Bangladesh for fuelwood and poles.

The initial plantations are by now 6-9 years old. The probable growth and yield of the species in Bangladesh have not yet been determined systematically. Since such information is necessary for scientific management of the plantations, the present models/tables were selected based on site indices to fulfill the basic requirements of forest management.

Materials and methods

Mangium is planted in Bangladesh at spacings of 1.5 × 1.5 m to 2.7 × 2.7 m in general. Permanent sample plots were laid out in the available plantations. The plots were square with an area of 0.05 ha each. All the trees in a plot were marked at diameter at breast height (dbh) with red paint and numbered at about 1.8 m above the ground with tin plates. Dbh of all the trees in the plot were measured by diameter tapes for succesive six years. Heights of the biggest 5 trees were measured for estimation of the dominant height and of 10 trees selected systematically for estimation of the mean height of the trees of the plot.

The number of permanent sample plots was not enough to forecast the growth and yield of the species. Therefore, a total of 113 temporary sample plots were laid out throughout the plantations to supplement the data. Plantations having maximum age ranges were selected. From each plantation three plots were selected at random. The plots were squares of 0.02 ha each. Diameters at breast height were measured by diameter tape and corrected to the nearest 0.1 cm for all the trees in the plot. The total heights of the two tallest trees in each plot were measured by a measuring stick and corrected to 0.1 m for the plots with dominant height of 8.0 m or less, and by Blume Leiss hypsometer corrected to the nearest 0.5 m for the plots with larger trees. The heights of the other trees were estimated from the heights of the trees measured.

Data collation

For statistical processing, information was derived for stand age (A), dbh of the mean tree (D), average dominant height (H), average stand height (mht), basal area per hectare (BA ha^{-1}), total volume yield per hectare (Vt ha^{-1}), above ground total green biomass yield per hectare (Biomass ha^{-1}), green biomass of the stem and branched per hectare (Bsb ha^{-1}), site index (S), and spacing of the trees (sp). The volume and biomasses of the individual tree were estimated using the volume and biomass equations for the species (Latif *et al.* 1993, Latif & Habib 1994).

For the selection of the best suited site index guide equation, the following models were tested:

$$\log (H) = b_0 + b_1 \log (A)$$

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

$$H = b_2 * (1 - e^{-b_1 * A})^{b_3}$$

Where b_0 = intercept,
b_1 = slope,
b_2 = asymptote,
b_3 = inflection point,
H = mean height of 100 dominant and codominant trees per hectare,
A = age of the plantation in years.

Among the above mentioned models, the best suited model was selected subject to the fulfilment of the statistical and biological requirements.

For the determination of the acceptable yield models, the site index model was derived first. This was followed by the derivation of stand dbh, stand height, basal area per hectare (*BA* ha^{-1}), total volume yield per hectare (*Vt* ha^{-1}), above ground total green biomass yield per hectare (Biomass ha^{-1}) and green biomass of the stem and branches per hectare (*Bsb* ha^{-1}). Step-wise and all probable combinations of the independent variables regression methods were used to select the best suited models subject to the fulfilment of the statistical and biological requirements. Different transformations of the variables either in the form of logarithm to the base *e*, 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.

Model validation

Statistical validation

Statistical validation was the first step done in validating the models. It included the anayses of variance, minimum residual mean square, the highest coefficient of determination (r^2) and the highest adjusted r^2.

Biological principle testing

The predicted values were plotted against age for different site indices. The biological requirement is that the yield curves should be sigmoid.

Independent test

Validation of the models was done using data from 30 separate sample plots. The actual values of these plots were collectively compared with the corresponding values predicted by the selected models. The comparisons were made with the help of the chi-square test of goodness of fit, paired t-test and absolute deviation per cent. These were also compared with 45-degree line test by plotting the observed values and the predicted values in the graph.

Results and discussions

The site index model 2 was found to be suitable for mangium in the forests of Bangladesh. The specific form of the equation is given by

$$\log (H) = 4.0218 - 3.1457/A^{0.4},\ r^2 = 0.8069$$

To obtain the site index for each plot, a reference age of 6 years was used and the specific equation is given as,

$$\log (H) = 1.536 + \log (S) - 3.1457/A^{0.4}$$

Where S = site index of an individual sample plot at the base age of 6 years.

The selected stand diameter (D), stand height (mht), stand basal area per hectare (BA ha^{-1}), total volume yield per hectare (Vt ha^{-1}), above ground total green biomass yield per hectare (Biomass ha^{-1}) and green biomass of the stem and branches per hectare (Bsb ha^{-1}) models along with their correspond-ing coefficients of determinations are given below:

$\log (D) = 3.4406 - 8.8679/A + 0.2918 * S/A,$ $r^2 = 0.9939$
$\log(mht) = 1.3594 + 1.0648*\log (S) - 3.5051/A^{0.4}$ $r^2 = 0.8939$
$\log(BA \text{ ha}^{-1}) = 4.1601 + 0.7844*S/A - 19.217/A,$ $r^2 = 0.844$
$\log(Vt \text{ ha}^{-1}) = 6.0885 - 17.647/A + 0.5691*S/A,$ $r^2 = 0.9123$
$\log(\text{Biomass ha}^{-1}) = 5.8759 + 0.3474*S/A - 12.3627/A$ $r^2 = 0.867$
$\log(Bsb \text{ ha}^{-1}) = 0.3227 - 1.3984*\log(S)*\log(A) - 27.0368/S +$
$2.2546 *\log(S) - 5.3516/A + 4.1643*\log (A),$ $r^2 = 0.886$

The stand diameter growth model explains 99.39% of the total variation. The stand basal area and volume yield models explain 84.4% and 91.23% of the total variation respectively.

Statistical validation and biological principle testing

The selected models satisfied all the statistical criteria. The predicted values were plotted against age for different site indices. The curves were found to conform with the ideal attributes of a biological yield curve. The yield curves were sigmoid. The yield curves also showed that at a given stand age, higher yield is expected on better sites.

Independent test

The computed chi-square, t-values, slope and absolute deviation per cent (AD %) for dbh, stand mean height (mht), basal area per hectare (BA ha^{-1}), total volume yield per hectare (Vt ha^{-1}), above ground total green biomass yield per hectare (Biomass ha^{-1}) and green biomass of the stem and branches per hectare (Bsb ha^{-1}) are given below:

Variable	Chi-square	t-value	Slope °	%AD
dbh	2.11	1.1	44.1	2.1
mht	1.99	1.0	45.1	2.2
BA ha^{-1}	4.73	1.4	43.3	3.3
Vt ha^{-1}	4.33	1.3	43.9	3.7
Biomass ha^{-1}	7.80	1.6	43.0	6.6
Bsb ha^{-1}	8.27	1.7	44.0	6.7

The computed chi-square and t-values were less than the tabular values ($x^2_{0.95, 29} = 17.71$ and $t_{0.95,29} = 2.045$). These imply that there is no significant difference between the actual values from the 30 test sample plots and their corresponding expected values as predicted by the models. Hence, the selected models conform with the set of data.

45 degree line test

Graphs comparing the observed values and the predicted values were plotted. It was observed that the models tend to make an angle of 45 degrees with the axes, meaning there is no significant difference between the actual and the predicted values. The models give underestimation of the values within the range of 2.1 to 6.7 %.

After the validation test, stand dominant height, stand height, stand diameter, stand basal area per hectare, total volume yield per hectare, above ground total green biomass yield per hectare and green biomass of the stem and branches per hectare were estimated and presented in Tables 1 - 7. The forest manager may readily get the values from the tables as desired rather than calculating them for general use. If the users know the average dominant height of the trees of a forest, they can estimate the site index of it using the dominant height-site index and age relationship model and from that they can estimate other necessary values using the models/tables given in the present article. The models may be improved by using data collected from a wide range of variation in stocking (number of stems per unit area), searching independent variables to get more precise estimate, etc.

The yield prediction model derived in the study could be satisfactorily used for mangium plantations within the limitations of the data used in the study. The yield prediction models and its use are recommended for stands of ages 1-9 years and site indices of 8.0 to 20.4 meters based on a base age of 6 years.

Table 1. Dominant height of mangium in the plantations of Bangladesh (m)

Age in years	Site index (m)				
	6	9	12	15	18
1	1.2	1.8	2.4	3.0	3.6
2	2.6	3.9	5.1	6.4	7.7
3	3.7	5.5	7.3	9.2	11.0
4	4.6	6.9	9.2	11.4	13.7
5	5.3	8.0	10.7	13.4	16.0
6	6.0	9.0	12.0	15.0	18.0
7	6.6	9.9	13.2	16.4	19.7
8	7.1	10.6	14.2	17.7	21.3
9	7.5	11.3	15.1	18.9	22.6
10	8.0	12.0	15.9	19.9	23.9
11	8.4	12.5	16.7	20.9	25.1
12	8.7	13.1	17.4	21.8	26.1

Table 2. Stand height for mangium in the plantations of Bangladesh (m)

Age in years	Site index (m)				
	6	9	12	15	18
1	0.8	1.2	1.6	2.1	2.5
2	1.8	2.8	3.9	4.9	5.9
3	2.7	4.2	5.7	7.3	8.8
4	3.5	5.4	7.3	9.3	11.3
5	4.2	6.4	8.7	11.0	13.4
6	4.7	7.3	9.9	12.6	15.3
7	5.2	8.1	11.0	13.9	16.9
8	5.7	8.8	11.9	15.1	18.4
9	6.1	9.4	12.8	16.2	19.7
10	6.5	10.0	13.6	17.2	20.9
11	6.8	10.5	14.3	18.2	22.1
12	7.2	11.0	15.0	19.0	23.1

Table 3. Stand diameter for mangium in the plantations of Bangladesh (cm)

Age in years	Site index (m)				
	6	9	12	15	18
1	0.0	0.1	0.1	0.3	0.8
2	0.9	1.4	2.1	3.3	5.1
3	2.9	3.9	5.2	7.0	9.4
4	5.3	6.6	8.2	10.2	12.6
5	7.5	9.0	10.7	12.7	15.1
6	9.5	11.0	12.8	14.8	17.1
7	11.3	12.8	14.5	16.4	18.6
8	12.8	14.3	16.0	17.8	19.9
9	14.2	15.6	17.2	18.9	20.9
10	15.3	16.7	18.2	19.9	21.7
11	16.3	17.7	19.2	20.7	22.5
12	17.2	18.5	20.0	21.5	23.1

Table 4. Stand basal area per hectare for mangium in the plantations of Bangladesh (m^2 ha^{-1})

Age in years	Site index (m)				
	6	9	12	15	18
1	0.0	0.0	0.0	0.0	0.4
2	0.0	0.1	0.5	1.5	5.0
3	0.5	1.1	2.4	5.3	11.7
4	1.7	3.1	5.5	9.9	17.9
5	3.5	5.6	9.0	14.4	23.1
6	5.7	8.4	12.5	18.5	27.4
7	8.1	11.3	15.8	22.1	30.9
8	10.4	14.0	18.8	25.2	33.9
9	12.8	16.6	21.6	28.0	36.4
10	15.0	19.0	24.0	30.4	38.5
11	17.1	21.2	26.3	32.5	40.3
12	19.1	23.3	28.3	34.4	41.9

Table 5. Total volume yield per hectare for mangium in the plantations of Bangladesh m^3 ha^{-1}

Age in years	Site index (m)				
	6	9	12	15	18
1	0.0	0.0	0.0	0.0	0.3
2	0.4	0.8	2.0	4.6	10.9
3	3.8	6.8	12.0	21.2	37.4
4	12.6	19.2	29.5	45.2	69.2
5	25.6	36.0	50.7	71.3	100.3
6	41.1	54.7	72.6	96.6	128.3
7	57.7	73.6	94.0	119.9	153.1
8	74.4	92.1	114.0	141.1	174.7
9	90.7	109.6	132.5	160.2	193.6
10	106.2	126.0	149.4	177.2	210.2
11	120.9	141.2	164.9	192.5	224.9
12	134.6	155.2	178.9	206.3	237.8

Table 6. Above ground total green biomass yield per hectare for mangium in the plantations of Bangladesh (t ha^{-1})

Age in years	Site index (m)				
	6	9	12	15	18
1	0.01	0.03	0.10	0.28	0.79
2	2.09	3.52	5.92	9.97	16.80
3	11.59	16.40	23.21	32.85	46.50
4	27.28	35.41	45.94	59.62	77.36
5	45.62	56.19	69.21	85.25	105.00
6	64.25	76.44	90.94	108.20	128.72
7	82.07	95.25	110.54	128.28	148.88
8	98.60	112.32	127.95	145.76	166.04
9	113.73	127.70	143.38	160.98	180.74
10	127.49	141.50	157.04	174.29	193.44
11	139.98	153.89	169.19	186.00	204.48
12	151.32	165.05	180.02	196.36	214.17

Table 7. Total green biomass yield per hectare of the stem and branches for mangium in the plantations of Bangladesh (t ha^{-1})

Age in years	Site index (m)				
	6	9	12	15	18
1	0.00	0.05	0.19	0.48	0.99
2	0.19	1.42	4.37	9.13	15.59
3	0.90	5.41	14.09	25.96	39.96
4	2.27	11.57	26.84	45.20	64.66
5	4.29	19.28	40.91	64.25	86.83
6	6.93	28.12	55.45	82.27	106.13
7	10.17	37.80	70.04	99.05	122.85
8	13.96	48.12	84.50	114.61	137.40
9	18.29	58.94	98.72	129.07	150.15
10	23.11	70.18	112.66	142.53	161.41
11	28.42	81.76	126.31	155.12	171.45
12	34.19	93.62	139.67	166.93	180.46

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