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Estimation of the Optimal Forest Rotation of Sissoo (Dalbergia sissoo) Plantations in Bangladesh

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Abstract
Using various criteria, the paper estimates the optimal rotation period for Sissoo (*Dalbergia sissoo*) plantations in Bangladesh. Plantations data were collected during 1999-2000 from purposively selected Forest Divisions aged at least 5 years. Under the present management system, mode of marketing, market mechanism and all economic criteria for Bangladesh as a whole, the optimal rotation of Sissoo tree is estimated to be at 8 years for fuel wood and 12 or 13 years for timber. If the Mean Annual Increment (MAI) is considered as rotation criterion, rotation period as 6 years for fuel wood and 11 to 13 years for timber are suggested. The elimination rates varied from 10% to 72% depending on plantation year, location, biotic interference and sissoo mortality. Irrespective of locations, it was revealed that the highest NPV (Tk 6395599), IRR (85%), B/C ratio (6.57), and L_e (Tk 2608031) start from the 13 year-old plantation.
Keywords: Sissoo, Optimal rotation, Forest management, Bangladesh.

1. Introduction

Sissoo (*Dalbergia sissoo*) is regarded as the most dependable ideal species for afforesting land along the banks of rivers, marginal lands, roads and highways, shade tree in tea gardens and rehabilitation of degraded woodland (Gupta and Karnik, 1983). It is a multipurpose tree and is extensively grown by farmers on agricultural field, homestead and community land for meeting their biomass and timber need (Tewari, 1994). From ecological viewpoint, sissoo trees are drought tolerant nitrogen fixers and effective in reclaiming sodic lands when planted in a large numbers (Mishra, et. al. 2002). These ecological benefits are expected to increase as drought, nutrient depletion and salinisation continue to reduce productivity in South Asian farmland (Mishra, et. al. 2002; Alauddin and Quiggin, 2008). From economic viewpoint, due to its fast growing nature and multiple uses, sissoo trees appeals mostly to growers, particularly in Bangladesh where 60% of private and 90% of public tree plantations are sissoo dominated (Anonymous, 2000). Rotation determination is, therefore, an important problem in forestry. The harvesting at the end of a rotation period of a plantation depends mainly on the growth rate of the species and the intended uses of the trees. The term 'uses' indicates economic uses after the maturity of trees. To explain the maturity of the trees from economic viewpoint, i.e. to determine the profit maximizing harvesting period, 'optimal rotation' criteria are applied. The optimal rotation period for long-term investment in forest plantations is fixed solely by economic criteria such as Net Present Value (NPV), Internal Rate of Return (IRR), Benefit-Cost Ratio (B/C), Land Expectation Value (L_e), Land and Timber Value (LTV_k) etc that originated from the Faustmann-Pressler-Ohlin Theorem (Johansson & Löfgren, 1985, p. 74). The current study aims to determine the rotation period for timber as well as fuel wood of Sissoo species planted in different locations of Bangladesh.

This paper is organized as: section 2 reviews literature, section 3 discusses methodology, section 4 discusses the results, and concluding words in the last section.

2. Literature Review

At 10% discount rate, Tewari (1994) found NPV, Gross Benefit Cost Ratio (GBCR) and IRR for sissoo plantations in Panjab (India) as Rs. 2705 per ha, 5.07 and 18.36%, respectively. In Gujarat (India), IRR, B/C and Pay- Back period (PB) for sissoo were found to be 20%, 2.90 and 10 years, respectively (Goswami & Singh, 1976). In Bihar (India), on the other hand, IRR was found to be 22.57 and number of trees per hectare was found as 2595 with an average diameter of 5.1 cm and height of 7.6 meter at 10 years rotation while at 20 years rotation, the IRR was found to be 20.06 having number of trees per hectare 865 with an average diameter of 12.2 cm and height of 13.7 meter. At rotation period of 20 years with intermediate thinning and without thinning the IRRs were found to be 22.06 and 14.38, respectively (Trivedi, 1986). Latif, et. al.(2000) measured the volume tables for sissoo species planted on the embankments and roadsides in the coastal areas of Bangladesh. From 202 randomly selected standing trees, the highest 55 sissoo trees were found with 15 meters of total height (H) and the highest 31 sissoo trees were found with 65 cm of girth at breast height (GBH). Again, the lowest 2 sissoo trees were found with 21 meters of total height (H) and the lowest 3 sissoo trees were found with 135 and 145 cm of girth at breast height (GBH). Later, Latif and Islam (2001) estimated the growth rate of sissoo species planted in the coastal side of Bangladesh. They found the girth at breast height (GBH), height (H), volume per tree (V) and mean annual increment (MAI) per tree are as 71.3 cm, 12.2 m, 0.2528 m^3, 0.0178 m^3 at 14.2 years old plantation, respectively. Surveying from 72 plantations, Hossain and Martin (2013) though could able to correlate sissoo volume estimate with region (Rangpur, Dinajpur, Nilphamari, Chuadanga and Khulna), plantation characteristics (plantation age, per cent mortality, per cent sissoo and tree density) and soil characteristics (texture, soil P^H and organic matter), they did not estimate the profit-maximizing rotation period of sissoo plantations in Bangladesh. This paper shall fulfill the gap by estimating the optimal rotation of sissoo plantations for the country as a whole.

3. Methodology of the Study

3.1 Methods of Data Collection, Sources of Data and Nature of Data Collected

The sample survey was conducted during 1999-2000. Five Forest Divisions namely, Rajshahi, Mymenshingh, Dinajpur, Chittagong and Jessore were selected purposively. From selected Forest Divisions, 3 to 9 years old different plantations were chosen randomly having at least 5 years old trees. Three sample plots, on an average 0.01 hectare each, were selected from each plantation to collect data on diameter (cm) at breast height (DBH) and total height (m). Sample plots were chosen from woodlot, community forestry and strip plantations across the embankments, along the roadsides and railways. The costs of nursery raising, plantation establishment, weeding, thinning, vacancy filling and maintenance were collected from respective Divisional Forest Office. The mode of marketing and market prices of sawn timber, round log and fuel wood of sissoo were collected from local market places with a designed schedule. The prices of round log and fuel wood were used in the analysis. The plantations were primarily recorded in kilometer, acre and hectare, but finally converted into hectare. Data on sissoo seedlings planted were found from plantation journal of Forest Department (FD), and number of existing trees was found from survey.

3.2 Technique of Analysis

To determine the optimal rotation period of sissoo plantations, various economic criteria have been applied, namely, Net Present Value (NPV), Internal Rate of Return (IRR), Benefit-Cost ratio (B/C), Land Expectation Value (L_e), Equal Annual Equivalent (EAE) and Land and Timber Value (LTV_k). The following formulas in Equations 1-3 (Gittinger 1974, p. 98) were used in the analyses:

Equation 1: NPV (Net Present Value) = $$\sum \frac{R_n}{(1+i)^n} - \sum \frac{C_n}{(1+i)^n}$$

Equation 2: IRR (Internal Rate of Return) = $$\sum \frac{R_n}{(1+i)^n} - \sum \frac{C_n}{(1+i)^n} = 0$$

Equation 3: B/C (Benefit Cost Ratio) = $$\frac{\sum \frac{R_n}{(1+i)^n}}{\sum \frac{C_n}{(1+i)^n}}$$

Where R_n is the returns every n years, C_n is the cost every n years, n is the number of years, and i is the interest rate.

Equation 4 (Gunter and Haney 1984, p. 68), Equation 5 (Gunter and Haney 1984, p. 72) and Equation 6 (Gunter and Haney 1984, p. 76) were also used.

Equation 4: EAE (Equal Annual Equivalent) = NPV $\left[\frac{i(1+i)^t}{(1+i)^t-1}\right]$

Where NPV is the Net Present Value, i is the interest rate, and t is the rotation period, where t= 1,…,n.

Equation 5: $L_e = \frac{Y_r + T_b(1+i)^{r-b} + I\left[\frac{(1+i)^r-1}{i}\right] - C_c(1+i)^{r-c} - e\left[\frac{(1+i)^r-1}{i}\right]}{(1+i)^r-1}$

Where L_e is the land expectation value, Y is the net yield at rotation age, T is the net value of intermediate cuttings, b is the age at which revenue is received, I is the annual income, C is the net value of intermediate cost, c is the age at which cost is incurred, e is the annual expenses, r is the length of rotation, and i is the interest rate as a decimal.

Equation 6: $LTV_k = \frac{a}{(1+i)^r-1}$

Where LTV_k is the land and timber value at age k, a is the amount of perpetual periodic payment, i is the interest rate, r is the rotation age and also, the period between periodic payments of amount a.

Tree volume (m^3) under bark (Vub) was estimated using Equation 7 (Latif et. al. 1995, p. 22):

Equation 7: Log (Vub) = -10.2398 + 2.100244 * log (D) + 0.780214 * log (H)

Where Vub is the volume under bark (m^3), D is the DBH (cm), H is the tree height (m), and log is the logarithm base 10.

The term 'elimination' is used to mean unauthorized felling. The elimination rate was determined using Equation 8:

Equation 8: $E_r = I_s - (P_s + T_t + N_d)$

Where E_r is the elimination rate in percentage, I_s is the initial planted seedling, P_s is the present stock, T_t is the number of trees thinned, and N_d is the number of trees that have naturally disappeared.

3.3 Assumptions

The interest rate, the cost of harvesting as a percentage of total value, the cost of processing as a percentage of the total value, and the number of trees per hectare were assumed to be 10%, 10%, 5%, and 1000 (for MAI), respectively. The conversion factors such as 1 m^3 = 7 mond (md), 1 mile = 1.609 km, 1 ha = 2.47 acres, and 1 mond = 37.3261 kg are important in this respect, where mond and mile are local units of measurement.

4. Results and Discussion

Both the mixed and mono plantations of sissoo were considered. In mixed plantations, the number of planted sissoo seedlings was, on an average, 48% of the total trees. The plantation aged up to 9 years was considered for pole post and fuel wood and more than 9 years old for timber.

Table 1: Market Prices of Timber and Fuel Wood of Sissoo

Locations	Market prices (Tk/md)	Market price (Tk/m^3)	
	Fuel wood	Round log	Sawn timber
Rajshahi	55	9534	17302
Chittagong	50	6797	14389
Mymensingh	45	4061	11476
Dinajpur	50	7062	15890
Jessore	50	9534	13771
Mean	50	7397	14565
S.D.	4	2277	2205
C.V.	7%	31%	15%

US $ 1= Tk. 53.96 in 2000. Source: Economic Trends (2001), Bangladesh Bank.

The market survey was conducted in the year 1999-2000. Market prices of timber and fuel woods of sissoo were shown in the Table 1. The average market prices of sawn timber, round log and fuel woods were found to be Tk. 14565 per m^3, Tk. 7397 per m^3 and Tk. 50 per mond, respectively.

Table 2: Basic Information of Sissoo Plantations in Bangladesh

Division	**Rajshahi**								
Plantation year	1981-82	1982-83	1983-84	1984-85	1985-86	1986-87	1989-90	1990-91	1992-93
Age (year)	18	17	16	15	14	13	10	9	7
Existing sissoo (number/ha)	1135	1024	2087	2404	2447	3739	5567	5567	5603
Elimination	26%	72%	55%	28%	49%	39%	20%	20%	20%
Vub (m^3/tree)	2.218	0.655	1.024	0.793	1.077	1.274	0.213	0.069	0.132
Total yield (m^3)	1445	439	3313	2847	3027	4926	171	110	1188
Yield (m^3/ha)	2517	670	2137	1907	2636	4765	1188	384	740
Division	**Mymensingh**			**Dinajpur**					
Plantation Year	1992-93	1993-94	1994-95	1985-86		1992-93	1993-94		1994-95
Age (year)	7	6	5	14		7	6		5
Existing sissoo (number/ha)	2219	2861	2281	1262		1121	2023		2690
Elimination	39%	27%	36%	49%		50%	35%		40%
Vub (m^3/tree)	0.116	0.140	0.068	0.171		0.095	0.116		0.090
Total yield (m^3)	190	359	64	1835		96	402		135
Yield (m^3/ha)	257	400	154	216		106	235		243
Division	**Chittagong**			**Jessore**					
Plantation Year	1995-96	1995-96	1995-96	1985-86	1986-87		1992-93	1993-94	1994-95
Age (year)	4	4	4	14	13		7	6	5
Existing sissoo (number/ha)	12260	12260	4904	3722	3722		1515	4035	1213
Elimination	20%	20%	20%	19%	19%		54%	10%	66%
Vub (m^3/tree)	0.054	0.028	0.054	0.39	0.73		0.14	0.11	0.07
Total yield(m^3)	117	182	108	1178	2282		158	486	48
Yield (m^3/ha)	657	339	263	1433	2732		215	426	81

Vub = Volume under bark

Sissoo plantations under this study were planted by FD at the earliest time on trial and error basis, when standard spacing was mostly found absent. This is why, number of existing trees per hectare was found substantially high, particularly in Rajshahi, Chittagong and Jessore divisions as shown in the Table 2. The elimination rates varied from 10% to 72%, the lowest elimination rate was found 10% in Jessore division for the plantation year 1993-94 and more than 50 percent elimination rates were found in Rajshahi division for the plantation year 1982-83 and 1983-84 and in Jessore division for the plantation year 1992-93 and 1994-95.

Table 3: Growth of Sissoo Plantations at Different Locations and Ages

Location	Age (yr)	DBH(cm)			Total Height (m)			Vub (m^3/per tree)	Total trees (number/ha)	Total Yield (m^3/ha)	MAI (m^3/ha)
		Max	Min	Mean	Max	Min	Mean				
Rajshahi	18	65.52	42.06	35.88	24.00	19.00	19.23	1.224	988	1209	68
	17	39.64	23.05	35.80	20.00	13.50	19.22	0.655	1024	670	39
	16	50.15	22.85	35.80	22.25	16.50	19.22	1.024	2087	2137	64
	15	46.51	18.20	30.02	22.75	12.50	18.60	0.793	2404	1907	53
	14	44.62	19.95	29.92	21.33	11.50	16.28	0.544	2477	1348	39
Dinajpur, Jessore, Rajshahi	13	41.39	19.01	29.68	21.00	9.50	16.08	1.000	3730	3746	77
	12	43.01	19.48	29.80	21.17	10.50	16.18	0.770	3104	2547	68
	11	42.20	19.25	29.74	21.08	10.00	16.13	0.890	3417	3147	84
Rajshahi	10	24.27	14.96	19.49	17.00	8.00	14.18	0.213	5567	1188	21
	9	19.41	10.52	13.11	12.50	90.00	10.96	0.069	5567	384	8
	8	21.84	12.74	16.30	14.75	8.50	12.57	0.141	5567	786	18
Mymensingh, Jessore, Rajshahi	7	22.89	11.32	16.88	17.00	8.09	11.51	0.121	2615	317	17
Dinajpur, Mymensingh, Jessore,	6	23.32	11.66	17.24	13.17	6.50	10.07	0.120	2973	358	20
Dinajpur, Mymensingh, Jessore, Chittagong.	5	19.39	9.96	13.89	11.72	5.95	8.78	0.075	2061	154	15

Max = Maximum, Min = Minimum, Vub = Volume under bark

Table 3 shows the DBH and total height at maximum, minimum and mean value, volume yield and MAI. The

mean value of total height and DBH were found to be 19.22 m and 35.80 cm in 16 years old plantations. The number of existing trees per hectare was recorded highest (5,567) in 8 year-old, 9 year-old, and 10 year-old plantation and lowest (988) in 18 year-old plantation in Rajshahi division. This may be due to illegal felling, the spacing and conversion of kilometer into hectare. It was found that the highest MAI (84 m^3/ha) was found at age 11 year and second highest (77 m^3/ha) at age 13 year plantation in Dinajpur, Jessore and Rajshahi divisions. For fuel wood, the highest MAI was found 20 m^3/ha at age 6 years. Thus, the rotation period has been suggested as 6 year-old for fuel wood and 11 to 13 year-old for timber based on MAI. Noticeably, at 5 and 6 years old plantation, having maximum DBH 19.39 cm and 23.32 cm respectively, sissoo trees are not only suitable for fuel wood but also for pole post and small logs in some locations.

Table 4: Economic Information of Sissoo Plantations in Bangladesh at Different Locations and Ages

Location	Age (years)	NPV (Tk.)	IRR	B/C	Le	EAE_{L_e}	EAE_{NPV}	LTV_k
	18	2049992	49%	6.40	449568	54816	249956	449568
	17	1685020	53%	6.40	415596	51810	210062	415596
	16	3942540	65%	6.54	1096681	104174	503922	1096681
	15	3608265	63%	6.41	1135657	149309	474392	1135657
	14	10141503	78%	6.57	3625204	492108	1376671	3625204
	10	953424	57%	2.34	598230	97359	155165	598230
	9	1697	10%	1.03	1249	217	295	1249
Rajshahi	8	63033	25%	1.90	55119	10332	11815	55119
	7	-45601	1%	0.76	-74693	-19704	-12029	-74693
	6	-54618	9%	0.57	-89462	-23600	-14408	-89462
Chittagong	5	-18183	1%	0.76	29784	-7857	-4797	-29784
	7	14170	21%	1.49	14936	3068	2911	14936
	6	47716	39%	2.16	61844	14200	10956	61844
Mymensingh	5	-1806	8%	0.95	-2959	-781	-477	-2959
	14	334191	51%	5.97	119461	16216	45365	119461
	7	-32662	12%	0.37	-34427	-7072	-6709	-34427
	6	-11449	3%	0.80	-14838	-3407	-2629	-14838
Dinajpur	5	8417	17%	1.19	13786	3637	2220	13786
	14	3036607	68%	6.41	1085472	147349	412208	1085472
	13	6395599	85%	6.57	2608031	367155	900363	2608031
	7	399	10%	1.01	421	86	82	421
	6	1226	11%	1.03	1589	365	281	1589
Jessore	5	-23803	10%	0.30	-38989	-10285	-6279	-38989

NPV = Net Present Value, IRR = Internal Rate of Return, B/C = Benefit-Cost Ratio, EI = Efficiency Index, L_e = Land Expectation Value, EAE_{L_e} = Equal Annual Equivalent based on L_e, EAE_{NPV} = Equal Annual Equivalent based on NPV, LTV_k = Land and Timber Value at age k.

US $ 1= Tk. 53.96 in 2000. Source: Economic Trends (2001), Bangladesh Bank.

As the dendro-ecological conditions vary at different locations, the NPV, B/C ratio, IRR, L_e EAE_{L_e}, EAE_{NPV} and LTV_k of plantations have been calculated at different ages and locations of Bangladesh (Kibria et. al. 2000, p. 22). In almost all areas, the NPV was found negative for the 5, 6 and 7 years of plantations as shown in Table 4. For 6 year-old plantation of Mymensingh, the IRR was found highest (39%). In the 14 year-old plantation of Rajshahi, NPV, IRR, B/C ratio, L_e, EAE_{NPV} and LTV_k were found Tk. 10141503, 78%, 6.57, Tk. 3625204, Tk. 5.57 and Tk. 1376671, 3625204, respectively, and the second highest NPV, IRR, B/C ratio, L_e and EAE_{NPV} were found in the 16 year-old plantation. In the 13 year-old plantation of Jessore, NPV, IRR, B/C ratio, L_e, EAE_{NPV} and LTV_k were found to be Tk. 6395599, 85% 6.57, Tk. 2068031, Tk. 6.57, Tk. 900363, and 2608031, respectively, and the second highest NPV, IRR, B/C ratio, L_e, EAE_{NPV} and LTV_k were found in the 14 year-old plantation. From these criteria, it can be inferred that economic rotation may be fixed at 13 or 14 years for timber and 6 years for fuel wood.

Table 5: Economic Information of Sissoo Plantations in Bangladesh

Plantation age (years)	NPV	IRR	B/C	Le	EAE_{L_e}	EAE_{NPV}	LTV_k
18	2049992	49%	6.40	449568	54816	249956	449568
17	1685020	53%	6.40	415596	51810	210062	415596
16	3942540	65%	6.54	1096681	140174	503922	1096681
15	3608265	63%	6.41	1135657	149309	474392	1135657
14	4504100	66%	6.32	1610046	218558	611415	1610046
13	6395599	85%	6.57	2608031	367155	900363	2608031
12	3674512	71%	4.45	1603130	232257	527764	1603130
11	1838104	41%	2.74	802190	116237	264029	802190
10	953424	57%	2.34	598230	97359	155165	598230
9	1697	10%	1.03	1249	217	295	1249
8	63033	25%	1.90	55119	10332	11815	55119
7	-6031	6%	0.96	-6357	-1306	-1239	-6357
6	12498	18%	1.33	16198	3719	2870	16198
5	-22599	1%	0.76	-37017	-9765	-5962	-37017

NPV = Net Present Value, IRR = Internal Rate of Return, B/C = Benefit-Cost Ratio, EI = Efficiency Index, L_e = Land Expectation Value, EAE_{L_e} = Equal Annual Equivalent based on L_e, EAE_{NPV} = Equal Annual Equivalent based on NPV, LTV_k = Land and Timber Value at age k.

US $ 1= Tk. 53.96 in 2000. Source: Economic Trends (2001), Bangladesh Bank.

Irrespective of these locations, the economic criteria and rotation age for Bangladesh as a whole were shown in Table 5. The rotation period at national-level is generated by summing-up divisional data. From the Table, it is revealed that the highest NPV (Tk. 6395599), IRR (85%), B/C ratio (6.57), L_e (Tk. 2608031) come from the plantation aged 13 years. The second highest NPV (Tk. 4504100), B/C ratio (6.32), and Le (Tk. 1610046) were found at age 14 year-old, while second highest IRR (71%) was found at age 12 year-old. At 8 year old plantation, the highest NPV, IRR, B/C ratio, and L_e as fuel wood were found to be Tk. 63033, 25%, 1.90, and Tk. 55119, respectively. Among the economic criteria, NPV, IRR and L_e are the important criteria for assessing the rotation period. In this context, the optimal forest rotation for sissoo may be suggested at 12 to 14 year for timber and 8 year for fuel wood.

5. Conclusion

The elimination rates varied from 10 to 72 percent depending on plantation age, location and biotic interference. High elimination rate might also be occurred due to sisso mortality in Bangladesh. During the period 1992-2000, sissoo mortality had greatly caused by soil-borne root-rot fungi, namely, *Fusarium solani* and *Ganoderma lucidum* (Basak, 1994; Webb and Hossain, 2005). The average number of seedlings planted per hectare was recorded highest value 12260 and lowest value 3078. The variation in number of seedlings may be due to the spacing and conversion of kilometer into hectare. If we consider the MAI as rotation criterion, rotation period may be suggested at the age 6 years for fuel wood and 11 to 13 years for timber. Considering the economic criteria for Bangladesh as a whole, 13 years for timber and 8 years for fuel wood may be suggested as rotation period. Planting sissoo trees is a risky initiative due to poor wood quality, high mortality rates and low rotation-age volume estimates (Webb and Hossain, 2005). On the other hand, sissoo may not be profitable option for plantation farmers of Bangladesh (Hossain and Martin, 2013). Under the current study, the rotation period of sissoo is important for those plantations planted at earliest period by FD. This study suggests for further research on determining optimal rotation based on economic as well as end-use criteria, and to reinvestigate the influence of region, plantation characteristics and soil characteristics on optimal rotation.

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