OPTIMAL HARVESTING SCHEDULES FOR A *GMELINA ARBOREA* PLANTATION IN A NIGERIAN TROPICAL RAIN FOREST

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ABSTRACT

A Linear Programming (LP) model was used to prescribe timber harvest in the management of an even-aged forest plantation. The plantation is being managed for timber production on fifteen years rotation and on a 5-year periodic planning.

The solution of the LP showed that about 5.8 × 10^7 m^3 of wood was maximized. The optimal solution prescribed 2,945 ha (20, 730, 202 m^3) to be cut in Period-I (1995-2000), 3,766 ha (22,158,071 m^3) in Period-II (2001-2005) and 2,515 ha (14,959,539 m^3) in Period-III (2006-2010). Two other feasible solutions were also worked out.

The volume per hectare of the plantation for *Gmelina arborea* was unusually large because the plantation was not thinned as at the time of the study.

Keywords:

Forestry plantation, harvesting schedule, environmental impact.

INTRODUCTION

Wood production from the Nigerian natural forests without any doubt has arrived at a crisis junction. The ever increasing demand for wood can no longer be met solely from her natural forests. The situation arose largely from over-exploitation of commercial timber species from the natural forests. Between 1970 and 1980, Nigeria witnessed an era of oil boom which led to the rapid expansion of her economy. The Federal and the State governments increased their spendings on the construction of buildings and roads. The establishment of three wood-based industries (i) Jebba Paper Mill Complex, (ii) The Nigerian Newsprints manufacturing Company in Oku-Iboku and (iii) The Nigerian National Paper Manufacturing Company in Iwopin, fueled the demand for wood in large quantitites with desired qualities. The Nigerian's awareness of this potential wood requirements, therefore, compelled a growing understanding of plantation forestry. In 1979, the Federal Government of Nigeria received the support of the International Bank for Reconstruction and Development towards the combined costs of three associated forestry plantation projects in Ondo, Ogun and Anamba States of Nigeria. The main objective of the plantation projects was to increase round wood production and to provide short fibre pulpwood for the mills in Nigeria.

Available records (Project Document) - showed that a total of 8,250 ha of *Gmelina arborea* plantation was established in the first phase of the project (1980-1986). The success story of the plantation establishment was so encouraging which led to substantial financial support from the World Bank and the African Development Bank during the second phase (1987-1994). An additional 5,400 ha of *Gmelina arborea* plus 600 ha of Pines were established (Fermecu, 1989).

Unfortunately, Nigerian National Paper Manufacturing Company did not go into paper production on schedule due to lack of technical know-how. The trees from some of these plantations are now over-grown and no longer suitable for paper production. The plantations are now being managed for timber production.

In order to enhance the successful management of the plantation and guarantee the steady supply of timber from the plantations, a viable exploitation rate has to be developed. The main objective of the present study is to develop optimal harvesting schedules for the *Gmelina arborea* plantations in Oluwa Forest Reserve - Ondo State, Nigeria by the use of linear programming (Bell, 1977). In the present study, the models will not cover costing and revenue minimization and maximization. Our main interest lies in the maximization of the woods from the established plantations through rational exploitation that will guarantee constant flow of woods on sustainable basis.

MATERIALS AND METHODS

I. Study Site

Oluwa Forest Reserve (7°30'N, 4°59'E) lies within the high forest zone in south western Nigeria. The climate of the area is moist monsoon with one to three months when there is less than 25 mm of rainfall per month. The annual rainfall varies from about 1,500 mm to 1,800 mm, most of it falling from March to October. Rainfall distribution is bimodal with a marked decline in August.

This reserve has a long history of uncontrolled exploitation (Hall & Redhead, 1971) and is described in the Plantation Project Document as 'low valued logged over high forest'. Uptill the end of 1984 a total of 9,226 ha with nine compartments of different age classes of *Gmelina arborea* were managed under an even-aged silviculture. The age (year of establishment) and size of each compartment are shown below:

Compartment	Year of Establishment	Hectarage
1.	1976	102
2.	1977	1008
3.	1978	850
4.	1979	985
5.	1980	1145
6.	1981	1062
7.	1982	1559
8.	1983	636
9.	1984	1879

II. Model Development

The compartments are to be exploited over a fifteen year period - rotation age of *Gmelina arborea* for timber (Aruofor, 1986). This means that each compartment is to receive a single cutting over the exploitation period. For simplicity, the planning is to be done on 5 years basis which means that the schedule will be done for 3 cutting periods of five years each. However, a compartment that is not completely cleared within a cutting period, can be extended to another period.

Let C_{ij} represent the amount of wood from compartment i during year j.

Let X_{ij} represent the fraction of compartment i to be Cut in the year j.

The, $C_{ij} X_{ij}$ represents the amount of wood cut from the ith compartment in the jth year.

Also, $\sum_{i=1} C_{ij} X_{ij}$ represents the total amount of wood taken from all the compartments in the jth year.

Finally $\sum_{i=1} \sum_{j=1} C_{ij} X_{ij}$ represents the total wood taken from all the compartments in all the years. It is this total wood which we intend to maximize.

Let the objective function be represented by z

$$Z = \sum_{i=1} \sum_{j=1} C_{ij} X_{ij}$$

The variable X_{ij} is constrained in a variety of ways:

1. The hectarage to be cut in each compartment can neither be negative nor exceed the total number of hectarage in each compartment.

   If ai represents the number of hectares in compartment i, it follows that $\sum_{j-1} a_i X_{ij} \leq A_i$, where A_i represents the total hectarage in compartment i and such that $X_{ij} \geq 0$ for all i and j.

2. There is need for restrictions on how much to be cut in each period so that wood volume can be adequately distributed over the cutting period. It, therefore, follows that $\sum_{i-1} a_i X_{ij} \leq B_j$ here

   B_j represents the maximum number of hectares which can be cut in the jth period.

The whole exploitation process can now be formulated as a linear programming problem thus:

Maximize

$$Z = \sum_{i=1} \sum_{j=1} C_{ij} X_{ij}$$

Subject to

1. $\sum_{j-1} a_i X_{ij} \leq A_i$, (i = 1, 2, ... 9)

1. $\sum_{i-1} a_i X_{ij} \leq B_j$, (j = 1, 2, & 3)

1. $X_{ij} \geq 0$ for all i and j.
   $j-1$

III. Estimation of the parameters (C_{ij}, a_i, A_i and B_j) of the model

The nine plantations which were established in the years 1976 to 1984 were treated as nine compartments. In each compartment, four sampling plots of size 20m × 20m were randomly laid and complete enumeration of all trees inside the plots was carried out. The height of each standing tree was measured using Alga altimeter and the diameter at breast height (1.5m) was measured using the conventional girth tape.

The projected wood volume per compartment and period was carried out by the use of the multiple linear regression model.

$$V = \beta_0 + \beta_1 A^{-1} + \beta_2 H + \beta_3 A^{-1} H \text{ (Ita, 1986).}$$

Where

A = Age of tree in the compartment

H = height of tree

β_0, β_1, β_2, β_3 are the regression coefficients.

The projected wood volume per compartment and period is presented in table 1.

Table 1. Tree volume (m^3) projection per compartment per period

Compartment	Period I (1995-2000)	Period II (2001-2005)	Period III (2006-2010)
1	1,166,882	1,173,200	1,202,992
2	11,390,320	11,531,600	11,638,368
3	8,865,500	9,001,500	9,083,100
4	9,357,500	9,515,100	9,609,660
5	9,745,095	9,928,295	10,038,215
6	10,660,356	10,830,276	10,932,228
7	12,752,620	13,020,601	13,151,724
8	4,998,960	5,100,720	5,161,776
9	9,960,579	10,261,212	10,441,603

The above values were used as estimates of C_{ij} - the coefficients of the objective function Z.

Fixing the values, the model becomes:

Maximize

$$
\begin{aligned}
Z = \; & 1,116,882X_{11} + 1,173,200X_{12}\; 1,202,992X_{13} \\
& +11,390,320X_{21} +11,541,600X_{22} +11,638,368X_{23} \\
& +8,865,500X_{31} +9,001,500X_{32} +9,083,100X_{33} \\
& +9,357,500X_{41} +9,515,100X_{42} +9,609,660X_{43} \\
& +9,745,095X_{51} +9,928,295X_{52} +10,038,215X_{53} \\
& +10,660,356X_{61}\; 10,830,276X_{62} +10,932,228X_{63} \\
& +12,752,620X_{71} +13,020,601X_{12} +13,151,724X_{73} \\
& +4,998,960X_{81} +5,100,720X_{82} +5,161,776X_{83} \\
& +9,960,579X_{91} +10,261,212X_{92} +10,441,603X_{93}
\end{aligned}
$$

Subject to

I

(i) $102 \sum_{j=1} X_{1j} \leq 102$

(ii) $1008 \sum_{j=1} X_{2j} \leq 1008$

$850 \sum_{j=1} X_{3j} \leq 850$

$$985 \sum_{j=1} X_{4j} \leq 985$$

$$1145 \sum_{j=1} X_{5j} \leq 1145$$

$$1062 \sum_{j=1} X_{6j} \leq 1062$$

$$1559 \sum_{j=1} X_{7j} \leq 1559$$

$$636 \sum_{j=1} X_{8j} \leq 636$$

$$1879 \sum_{j=1} X_{9j} \leq 1879$$

II

(i) $102X_{11} + 1008X_{21} + 850X_{31} + 985X_{41} + 1145X_{51} + 1062X_{61} + 1159X_{71} + 638X_{81} + 1879X_{91} \leq 9226$

(ii) $1008X_{22} + 850X_{32} + 985X_{42} + 1145X_{52} + 1062X_{62} + 1159X_{72} + 638X_{82} + 1879X_{92} \leq 9226$

(iii) $102X_{13} + 1008X_{23}\ 850X_{33} + 985X_{43} + 1145X_{53}\ 1062X_{63} + 1159X_{73} + 638X_{83} + 1879X_{93} \leq 9226$

III $X_{ij} \geq 0$ for all i and j.

RESULTS

The linear programming problem was solved on a personal computer. Summaries of the prescribed solution plus two other feasible solutions are presented in Table 1a, 1b and 1c.

The prescribed optimal harvesting regimes were 2,945 ha, representing about 20,730,202 m^3 of wood for Period I (1995-2000). For Period II (2001-2005), 3766 ha with wood content 22,158,071 m^3 was prescribed. The harvesting for Period III (2006-2010) was put at 2,515 ha with wood content 14,959,539 m^3.

Harvesting for Period I are to be carried out in compartments 1, 2, 3 and 4. The hravests for Period II are to be conducted in compartments 5, 6 and 7 while the final cutting for Period III will take place in compartments 8 and 9.

The other two feasible solutions recommend similar cutting regimes. These solutions are smaller wood removals in Period I and Period II than the wood removals for the optimal solution. They however, prescribed higher removals in the third period.

Table 1a. Optimal cutting shcedules

Compartment	Period I (1995-2000)	Period II (2001-2005)	Period III ((2006-2010)	Total
1	102			102
2	1008			1008
3	850			850
4	985			985
5		1145		1145
6		1162		1162
7		1559		1559
8			1879	1879
Total	2945	3766	2515	9226

Table 1b. Feasible cutting schedules I

Compartment	Period I (1995-2000)	Period II (2001-2005)	Period III ((2006-2010)	Total
1	102			102
2	1008			1008
3	425	425		850
4	493	492		985
5		1145		1145
6		531	531	1062
7		780	779	1559
8			636	636
9			1879	1879
Total	2028	3373	3825	9226

Table 1c. Feasible cutting schedules II

Compartment	Period I (1995-2000)	Period II (2001-2005)	Period III ((2006-2010)	Total
1	102			102
2	1008			1008
3	850			850
4	985			985
5		1145		1145
6		1062		1062
7		880	779	1659
8			636	636
9			1879	1879
Total	2945	3087	3294	9326

Sensitivity Analysis

It is not uncommon for wanting to change the developed decision model. Conditions often change, particularly in harvesting a plantation over years. Some of the causes for change include resources availability as occasioned by compartment size and the quantity of wood in each compartment. In this study, firstly, we varied the volume of wood available while keeping the size of the compartment fixed. Secondly, we varied the size of each compartment and fixed the quanity of wood taken from each compartment.

The following range of values for the hectarage and wood volume (see table 2) would have to be maintained in the optimal solution.

Table 2. Sensitivity analysis for the objective coefficients and the constraints

Compartment	Wood Volume (m^3)			Hectarage	
	Minimum	Original	Maximum	Original	Maximum
1	0.1 m	1.1 m	Infinity	102	6383
2	10 m	11 m	"	1008	7289
3	4.4 m	4.4 m	"	850	7131
4	4.7 m	4.7 m	"	985	7266
5	8.9 m	9.9 m	"	1145	6605
6	5.4 m	5.4 m	"	1062	6522
7	6.5 m	6.5 m	"	1559	7019
8	4.1 m	5.1 m	"	636	7342
9	9.0 m	10 m	"	1879	8590

m = Million

As expected, the maximum wood volume for each compartment is unbounded above. The minimum wood volume in five of the compartments (3, 4. 5, 6 and 7) coincided with the original solution for the LP. The remaining compartments (1, 2, 8 and 9) had lower minimum values. However, the maximum value for the amount of land in each compartment is bounded above, which in practical terms, puts an upper limit on the wood volume.

DISCUSSION/CONCLUSION

The unusually large wood volume per hectare of the plantation resulted from inadequate forest plantation management. The plantation was not thinned as at the time of the study (over 12 years). In Nigeria, there is limited or negligible forest management particularly plantation (Kio, 1978; Okojie, 1981). The conversion of many of Nigeria's moist rain forests to exotic species like Pine, *Eucalyptus*, *Tetcona grandis* and *Gmelina arborea* poses new problems. For resource-poor countries of the sub-saharan Africa, fertilization and thinning are yet to be accepted as management practices of merit. This situation puts a serious doubt as to the productivity of these plantations in the long-run.

However, the existence of thousand of hectares of forest plantations in a country like Nigeria, which has suffered from severe over exploitation of its existing indigenous trees, has some socio-economic benefits. These benefits include:

i. accessibility of previously inaccessible villages due to link roads which were built during plantation establishment. This situation improved the marketing of farm-produce derived under departmental taungya (a practice of growing arable crops with trees) with positive effects on their standard of living.

ii. improvement of health services in the villages due to the establishment of clinics which enhanced regular visits of medical doctors to the forestry workers (Adeola, 1992).

The environmental impacts of clear-felling of forest compartments of plantations is another issue of great concern. Clear-felling will definitely lead to soil erosion and loss of soil fertility with severe consequences on the future productivity of the forest plantations. The present state of knowledge of plantation forestry in Nigeria cannot guarantee that *Gmelina arborea* can be grown perpetually on the same site. Hence, the establishment of these plantations in a moist natural forest is like a journey from the known to the unknown. It is well known that our natural forests have been over-exploited which has resulted in low productivity (Osho, 1991, 1995). Is the conversion of such declining natural forests to forest plantations a permanent solution to our wood shortage? A controlled exploitation to reclaim a declining rain forest as against the conversion of the natural forest to plantation would appear more sensible (Osho, 1995). Perhaps, this issue will not be resolved until we gain more knowledge and experience of plantation management in Nigeria in another one or two decades. In the interim, uncertainties about meeting our future wood requirements will remain.

It can be concluded that linear programming, though very costly and time-consuming during data collection and preparation, is nevertheless of good technique for generating information both for short-term and long-term planning and decision making in logging management in Nigeria.

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