Economic evaluation of two management strategies of *Acacia nilotica* (L.) plantations along the Blue Nile south of Sennar Dam, Sudan

By

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Major supervisor    Co-supervisor
Dedication

I dedicate this work to the souls

of my father,

my mother

Zienab Bit El-Houri

and

my professor

Ahmed El-Houri Ahmed
Declaration

I, here by, declare that this research is my own work and it hasn't been submitted to any other institute for any kind of degree.

Dafa-Alla Mohamed Dafa-Alla
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Several institutions and individuals have contributed to the successful end of this study. I would like to extend my appreciation to the University of Juba for providing the funds of the study. My gratitude is extended to the Forest National Corporation, the General Director Dr. Abdelazim Mirghani for personal motivation and for financial support for the research; the technical and support staff, both at the Head Quarters and states, for their invaluable support during periods of information gathering and field work. Special appreciation is extended to my supervisors Dr. Huda A. Sharawi and Dr. Abdalla M. Eltayeb for their continuous and constructive guidance during the course of the study. The staff of the National Seed Center deserves distinctive salute for their support. Special gratitude is extended to the family of the Faculty of Forestry and Faculty of Higher Studies at the University of Khartoum. My family, the ever supporting wife Dr. Nawal K.N. Al-amin, my children Mohamed, Ahmed and Musaab, who suffered the hard times of my absence and the stress of the study, deserve distinctive thanks, at least.
Abstract

This study was concerned with the plantations of *Acacia nilotica* grown for sawlog -to produce railway sleeper- production along the Blue Nile, South of Sennar dam, Sudan. The overall objective was to determine the best management strategy of the plantations that maximizes financial returns. Primary data was collected using standard work study techniques and inventory methods. Secondary data used included previous studies on yield tables and volume estimations. The study used the criterion of net present value (NPV) for determination of financial rotation, and for evaluating different management strategies. The research applied comparative statistics to assess relative stocking of existing stands.

The research revealed that the operations of seed sowing and singling were the most expensive forest operations involving 5.8 and 7.8 mandays per feddan, respectively. Log transport was the most expensive sawmilling-related operation involving 36 mandays and 3 machine days per feddan. With the current conversion factor of state sawmills of about 40%, the technical rotation of stands of site index 22 to produce sawlogs large enough to yield the maximum of a single sleeper was estimated to be within a range of 25-36 years. That of stands of site index 25 to yield the maximum of two sleepers falls within the range 25-36 years. Stands of site index 28 are technically suitable to produce sawlogs large enough to yield the maximum of three sleepers within age range of 29-36 years. These results exclude stands of site index 16 and 19 from producing saw logs for sleeper production. *A. nilotica* stands under present management show low relative stocking and yield per feddan, low millable percentage of final cut (47%) and rotation age dropped to 25-27 years.

The financial rotation was determined as 33 and 26 years when *A. nilotica* stands are managed for sawlog production under Foggie management strategy (FMS) and Jackson management
strategy (JMS), respectively. Addition of capitalized net income from sawmilling operations for production of Sudan railways sleeper reveals that JMS is financially more attractive (95.1, 75.3 thousand Dinars) than FMS (88.3, 71.2 thousand Dinars) in more productive stands of site index 28 at both high and low levels of management, respectively. FMS is financially superior (29.2, 18.8 thousand Dinar) in less productive stands of site index 22 than JMS (25.1, 14.4 thousand Dinar) at both high and low levels of management, respectively. JMS and FMS applied to stands of site index 25 generated very close NPVs per feddan (59.0 & 59.2 thousand Dinar) at high level of management and low level of management (46.7 & 45.5 thousand Dinar). The use of taungya practice in establishment of A. nilotica stands, advancement of thinning in stands with better site qualities, and their combination improve their overall profitability relative to NPV of the system without them.

A number of policy and practical implications of the findings of this research are evident, First, A. nilotica forests need to be reorganized on the basis of site index and sawlog production be concentrated on stands of site index 28 and 25 while stands of site index 16 and 19 be assigned for firewood production. Second, the system of A. nilotica forests should be treated as inseparable continuum of sawlog-sleeper production. Third, Jackson Management Strategy is financially more attractive and should be adopted for the treatment of stands of site indexes 28 and 25 managed for sleeper production.

الخلاصة

تم تحديد النجاح العلمي للزراعة في النيل الأزرق بالسودان الجنوبية بفضل مناقشة مقارنة دراسة عمل ودراسة النتائج في المالية. استُخدمت دراسة caso STUDY في دراسة 28 عامًا في ولاية سكار، جنوب السودان. الأفكار التالية: نقل الجودة، النشاط، والدور. النتائج تتيح مقارنة العمل بالسودان وتشجيع التحسين في القيادة. النتائج تتيح تحليل العملية والدور الهادئ لدراسة النتائج ودراسة النشاط.

البحث

هناك عدة أهداف في هذه الدراسة، حيث يتم تحديد النجاح العلمي البدني في جنوب السودان. الأفكار التالية: نقل الجودة، نشاط، دور. النتائج تتيح مقارنة العمل بالسودان، وتشجيع التحسين في القيادة. النتائج تتيح تحليل العملية والدور الهادئ لدراسة النتائج ودراسة النشاط.

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الدراسة تشمل نقل الجودة، النشاط، دور، ودور. النتائج تتيح مقارنة العمل بالسودان، وتشجيع التحسين في القيادة. النتائج تتيح تحليل العملية والدور الهادئ لدراسة النتائج ودراسة النشاط.

النتائج

تأتي النتائج في المالية والدور والتغييرات، حيث يتم تحديد النجاح العلمي البدني في جنوب السودان. الأفكار التالية: نقل الجودة، نشاط، دور. النتائج تتيح مقارنة العمل بالسودان، وتشجيع التحسين في القيادة. النتائج تتيح تحليل العملية والدور الهادئ لدراسة النتائج ودراسة النشاط.

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Title: Economic evaluation of two management strategies of Acacia nilotica plantations grown for saw log production along the Blue Nile, south of Sennar Dam, Sudan.

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Chapter One: Introduction

1.1 Background:

The natural vegetation of the Sudan plain represents a gradient, from north to south following the rainfall amount, of increasing density and species richness. It begins with the desert and ends with semi-tropical vegetation. Much of the original plant succession has enormously deteriorated. The main causes are the heavy utilization pressures of increasingly growing human and livestock populations on the plant resources for biomass energy, building material and grazing. The population of Sudan is predominantly rural and lives off the land resources. Rain fed agriculture, woodcutting, internal trade in forest products and nomadic and semi-nomadic livestock production in the rangelands are the main forms of employment in rural Sudan (Beshir, 2001).

Forestry plays an important role in the national economy. This role is apparent in its contribution to national energy needs, balance of payments through direct foreign exchange earning, wood supply for construction, and employment generation (FNC and FAO, 1995). When marketable forests products are considered, the contribution of forests to national economy is manifested in the provision of 78 % of the national energy balance and 33 % of the national livestock alimentary needs (Beshir, 2001). The World Bank (1986) estimated that more than 1700000 of the population are engaged in forest related activities. In addition, forests provide almost all building materials in rural areas.

The contribution of the forestry sector to the Gross Domestic Product (GDP) is often underestimated in the National Accounting. According to the Ministry of Economics and Finance (MEF) it was around 3.3 % for 1999. However, with due consideration to the outputs directly
collected and/or consumed by local communities, the contribution of forests of the Sudan to national economy was estimated to be around 12% of the national GDP (FNC and FAO, 1995).

Legally constituted forest reserves make only 2.8% of the country's land area. The forest reservation process that started in 1923 was only able to settle and finally gazette 1.26 million ha by 1993. This is equivalent to 0.5% of the total land area of the country. By 1999 the fully reserved forest area reached 3.9 million ha. Another 4.62 million ha are under the process of registration. This amounts to only 3.5% of the total land area of the country. Of the total reserved forest area about 7.7 million hectares are in northern States and are classified as Riverine forests (amount to 523 thousands hectares which are under management plans), Montane forests (amount to 180 thousands hectares of which only the plantation at Jebel Marra forest is under management plan) and Rainfed Dhara forests that amount to 7 million hectares (Beshir, 2001).

Specific composition is known mostly for the river forests where the composition is mostly *Acacia nilotica* (locally known as Sunt) in its various subspecies (Beshir, 2001). *Acacia nilotica* species belongs to the family Mimosaceae. According to El Amin (1976) four subspecies are recognized: Subspecies *nilotica*, Brenan; Subspecies *tomentosa*, Brenan; Subspecies *astringens*, Roberty; Subspecies *subalata*, Brenan. Sunt is indigenous to the region, and given favorable conditions, regenerates naturally in profusion. The outstanding characteristics of Sunt is that it can withstand prolonged flooding, a characteristic shared by a few other species (Jackson, 1959). Variety adansonii prefers deep sandy-loamy soils, but also on loamy, lateritic or calcareous sites. Variety tomentosa prefers clay, alluvial soils and tolerates long periodical inundations. It is a tree that prospers on depressions and river beds,
on the banks of seasonal ponds (Von Maydell, 1986). According to El Amin (1976) subspecies *nilotica* is mainly found along the White Nile while subspecies *tomentosa* is mainly found along the Blue Nile. Sunt has been found to be the most valuable timber producing species in the Sudan. An ability to regenerate successfully on flooded sites along the Nile and its tributaries, coupled with timber properties that satisfy most of the utilization standards make the species the most important in the economy of the Sudan (Elsiddig and Hethrington, 1985).

1.2 Sunt forests of the Blue Nile River:

According to Jackson (1959) a high Blue Nile flood in 1904 caused profuse regeneration of Sunt in many of the basins and this was the origin of most of the "natural" Sunt forests found in the area, in which exploitation started in the thirties to supply half-round sleepers to the construction of Jebbel Aulia dam, and to produce Sudan Railways sleepers (SRS), pick helves, and sunt bark.

1.2.1 Area and distribution

The Blue Nile River is bordered by a flood plain varying from nothing to a kilometer or so in width and most of the forests are on the flood plain (Jackson, 1959). The best forests of Sunt are along the Blue Nile south of Sennar. In these areas the following zones can be distinguished (A. El Houri Ahmed, 1989):

(a) The "gerf" or silt bank separating the basin from the river. This is only flooded when the river is exceptionally high, but obtains water by infiltration. On this zone Sunt grows rapidly.
(b) The gerf slope (Gs) between the "gerf" and the bottom of the basin (maya). In this zone the amount of flooding varies from year to year, but in general the lower contours are flooded almost annually, while the higher contours are only flooded in years of high flood. The rate of growth of Sunt is not quite as high as on the gerf.

(c) The "maya" itself where flooding is usually above the optimum for Sunt.

(d) The Karab slope (Ks) which is the zone above the "maya" on the inland side. This is generally similar to zone (b) but the soil has more clay and less silt, and so growth is usually poor.

(e) The "hadab" which is the inland edge of the basin. Only flooded in years of high flood and is too dry for optimum development of Sunt.

Foggie (1969) gives estimates of the areas of the riverine forests along the Blue Nile (table 1).

Table 1. Areas in feddans of riverine forests along the Blue Nile (after Foggie, 1969).

<table>
<thead>
<tr>
<th>Category</th>
<th>Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sunt or potential Sunt stands</td>
<td>19336</td>
</tr>
<tr>
<td>Other species</td>
<td>337</td>
</tr>
<tr>
<td>Blanks, mainly permanent Maya's</td>
<td>1395</td>
</tr>
<tr>
<td>Gerf plantations, mainly <em>Eucalyptus</em> spp., Bamboo, Neem and Mahogany</td>
<td>2077</td>
</tr>
<tr>
<td>Natural scrub</td>
<td>1131</td>
</tr>
<tr>
<td>Total</td>
<td>24276</td>
</tr>
<tr>
<td>woodlands on eroded Karab</td>
<td>8858</td>
</tr>
</tbody>
</table>

Forty-four reserves of Sunt forests are found along the Blue Nile south of Sennar Dam with a total area of 21031.484 feddans (8833.22 ha), thirty-seven reserves are situated north Sennar Dam with a total area of 14314.106 feddans (6014.33 ha) and twelve reserves situated along the White Nile with an area of 93020 feddans (39084.03 ha). Almost 90% of these reserves
are situated in an alternating manner along the banks of the two rivers as detached areas (FNC, 1998).

1.2.2 Objective of management

The plantations along the Blue Nile south of Sennar dam are managed under working plans which aim at producing saw logs that are capable of yielding railway sleepers mainly. To reach sawlog sizes Sunt trees in the plantations have to be thinned. (A. El Houri Ahmed, 1976). On the Blue Nile north of Sennar basins Sunt forests are also found, but the basins tend to be shallower and the growth poorer (A. El Houri Ahmed, 1989) and hence managed mainly for firewood production. Beside the sleepers, many other sawn products for local consumption are made from Sunt wood at both public and private sawmills. Considerable amount of firewood is produced from plantations managed for sawlog production as by product. Sunt pods (locally known as Garad) are used in leather industry inside the Sudan. In 1993/94, 20 380 sacks were collected. Of the later 685 units were exported in 1999 with a total value of US$. 400,000 (Beshir, 2001). Railway sleeper has been the main sawn product of Sunt plantations. Two classes of sleeper are in use. The most important product is the SRS. There is also a large demand for sleepers for the light railways of the Sudan Gezira Board (SGBS). The Sudan Railways Corporation (SRC) has been the single most important consumer, while the FNC has continued to be the only supplier of locally produced sleepers.

A management strategy (Green in: Jacques and Stoecker, 1997) is defined to include the initial planting density, the number of thinnings, the age of each thinning and the remaining basal area after each thinning, and the age of final clear cut. Several studies have been conducted on the plantations of Sunt along the Blue Nile aiming at prescribing the management strategies that best suit the management objective. Part of these prescriptions was based on site quality classes
(Q.C.) while others use the site index criterion. Foggie (1969) stated that "All existing Sunt stands were assessed by dominant height attained and age, according to this, and through it was found impossible to stock-map all quality classes individually. It was found possible to determine and stock-map all good Sunt stands which are capable of producing railway sleeper logs on a fairly short rotation which were all between QC I and QC II/III, and mediocre crops which were capable of producing railway sleeper logs eventually on longer rotation. These were largely QC III with some QC III/IV, and poor crops which were most unlikely ever to yield sleeper size logs, comprising the rest of the III/IV and IV quality classes. The proportions by area occupied by these are good 52.3%, mediocre 36.9% and poor 10.8%. The average rate of growth, which may be used for the sleeper timber producing crops, will be that of quality class II or fractionally less".

1.3 The problem statement:
The main problem facing forest resource development in the Sudan is the lack of accurate statistics on forest products and the inability to produce confident forecasts of production. Although Sunt is one of the main commercial species few research works has been done to improve this situation (Elsiddig, 1984). Earlier studies on Sunt were concerned with management for maximum wood production, with rotation lengths prescribed for this objective specifically. Even for this objective there was a lack of consensus on the optimum technical rotation that would produce saw logs large enough to produce railway sleepers. Decisions on management objective, rotation length, thinning regime, establishment methods and other silvicultural and exploitation aspects were not usually based on economic studies. The very basic data on unit cost of plantation raising and sawmilling operations are lacking.
While there is a range of technically acceptable rotation age that produce logs large enough to produce railway sleeper, the felling age that maximizes the returns to the limited land resources utilized in the timber production process for different management objectives is necessary. The latter is not yet specifically known. Although many studies have been conducted to determine biological optimum rotation (Jackson, 1959; Foggie, 1969; Goda, 1982 and Eltayeb, 1985) none of them has examined the economics of adopting such a rotation.

The historical contribution of the forestry sector in Sudan to the national economy was dominated by the earnings of the export of Gum Arabic as a non-timber product, on the one hand, and the provision of wood energy, on the other hand. In 1999, 17.899 million tons of woodfuels were consumed, representing over 70% of primary energy consumption (Ministry of Energy and Mining, 2001). By product analysis, Woodfuels (firewood and charcoal) consumption in 1994 accounted for 87.5%, while construction, maintenance and furniture wood accounted for 7.2%, 3.8%, and 1.5%, respectively (FAO & FNC, 1995).

Recent petroleum explorations in Sudan are expected to create a shift towards the use of petroleum-based energy alternatives. The recent price reduction of Butane gas is expected to influence the demand on fuel wood. The SudaGas project undertaken by the FNC aims to make gas cookers and cylinders more accessible to households. Given the significant share of the household sector in energy consumption (89.4%) eventually raises the question of the necessity of establishing fuel wood projects in the future, including Sunt. Already, the central government has declared policies towards the use of petroleum-based energy alternatives.
The import of wooden sleepers and the production of constituted sleepers (for that a producing plant is under installation by the SRC) will jeopardise the use of wooden sleepers. This is even supported by the fact that the local supply of sleepers at present falls short of the actual demand by the SRC. The wooden sleeper local industry is characterized by a monopsony structure on the side of product demand where a buyer is the only buyer in a market and a monopoly structure on the side of product supply where a single seller the product of which has no close substitutes (Kohler, 1990) However, both parties are public institutions. Therefore, decisions on sleeper supply should be made with due consideration to national interests.

The economic viability of the objective of producing saw logs from Sunt plantations with a rotation as long as 30 years or more has been questioned. There is a growing concern and debate about this subject and a decision has to be taken to support the existing system or disprove it. The doubts stem from the concerns that alternative land uses of these forestlands, particularly the use of Gerf lands for horticultural and vegetable crops, may provide more returns to the national economy in shorter rotations. While technical rotation has been recommended to extend to 35 years (Booth, 1949; Foggie, 1969), 30 years (Jackson, 1959), or 25-30 for Gerf slope and Karrab slope, and 30 -35 for Maya site type (Goda, 1987), the felling age of the current practice has dropped to 25-27 years irrespective of site quality.

The absence of proper management plan since the seventies of last century, and the adoption of the approach of annual felling schedules have resulted in a wide variation of thinning intervals and intensities and a wide variation in the area to be felled and planted annually (FNC, 1998). The problem arises that the final crop trees of the current growing stands may not achieve the target diameter required to produce railway sleeper, on one hand. On the other hand, because of poor tending and thinning operations the status of current stands may
not justify retaining them to the end of the rotation. Furthermore, poor management results in lower productivity of sleeper-logs per unit area. Consequently, FNC either assigns larger annual felling coupes, or stick to specific annual felling coupes area at the expense of production of sleeper-producing sawlogs. Either cases leads to divergence from the prescribed management plans, which in turn has a direct bearing on its basis of sustained annual yield and on the profitability of the system.

1.4 Objectives and scope of the study:
The main objective of this study is to determine –from financial perspectives- the best management strategy of Sunt plantations, grown along the Blue Nile River between Sennar Dam in the north and Roseries Dam in the south, for a product mix of saw logs -capable of producing railway sleepers- as a main product, sawn timber - for local use- and fuelwood.

The scope of the study is limited to evaluating two management strategies from FNC perspective. The strategies (base models) are Foggie Management Strategy (FMS) which involves a rotation of 35 years and eight thinnings at 6, 9, 12, 15, 18, 21, 24 with the last thinning prescribed at age 27 (Foggie, 1969) and Jackson Management Strategy (JMS) which involves a rotation of 30 years and five thinnings at 6, 9, 12, 15 with last thinning prescribed at age 20 (Jackson, 1959). Five changes in basic production assumptions (alternative models) are introduced into the base models mentioned above. The changes aim to address the effect of establishing Sunt plantations through taungya, the advancement of thinning by one year in the most productive stands of site index 28, a combination of both, delaying of regeneration, and change in yield per unit area. For the later the yield of the final felling compartments of present stands is used to evaluate the profitability of the present practice relative to yield prescribed in yield tables of Sunt plantations.
To achieve the main objective the research addresses the following specific objectives:

1. To carry out work and time studies to determine inputs and outputs of the production processes of establishment through harvest and sawmilling in order to bridge the gap in information regarding costing of operations which has been an obstacle facing FNC and researchers. This implies determining the magnitudes of factors of production required per unit area or unit of output and estimate the operational and other costs of Sunt plantation establishment, tending and harvesting; skidding, log transport and sawmilling. In addition, the research aims at generating sufficient data on the pricing policy, price constituents and, timing and kind of wood product mix obtained from Sunt stands of different site indexes.

2. Determination of the technical rotation range for each site index that is suitable to yield saw logs capable of producing SRS.

3. Determination of optimal rotation of Sunt plantations managed for the production of saw logs capable of producing SRS based on prescribed yield tables for relevant site indexes and with land being the fixed factor of production. This involves: (a) Estimation of different percentages of millable and non-millable wood relative to crop age and site index and (b) determination of the financial rotation age for sawlog and sleeper production.

4. Determine the productivity status of the existing Sunt plantations grown along the Blue Nile River for sawlog production in terms of relative stocking i.e. diameter at breast height (dbh), stem number per hectare, basal area per hectare, mean height and volume per hectare for different ages and site indexes and compare it with the prescribed ones.

5. Carry out a financial cost benefit analysis for the two prescribed strategies, for introducing taungya in crop establishment, advancement of thinning in stands of high site quality, a combination of taungya and advanced thinning, delaying of regeneration and change in
yield per unit area using the above findings and applying the net present value (NPV) criterion.

1.5 The research questions:

- What are the nature, magnitude and timing of cost elements employed in, and income elements generated through, establishment, tending and utilization of Sunt plantations grown along the Blue Nile River for sawlog and railway sleeper production?
- What is the technical rotation age for the production of sawlogs from sunt stands of relevant site indexes?
- What is the financial rotation age of Sunt plantations grown mainly for sawlog production and some other products from the FNC perspective?
- What is the relative stocking and yield of Sunt plantations under present management? And what is the magnitude of deviations from rotation age prescribed by Jackson (1959) or Foggie (1969) and what is its impact on sawlog and consequently railway sleeper production? What is the financial NPV per feddan of Sunt stands under present management?
- What is the financial NPV per feddan of Sunt stands of various site indexes grown for sawlog and railway sleeper production mainly and some other products from the FNC perspective for each of FMS and JMS base models? What effects the introduced changes bring into the NPV per feddan?

1.6 The research hypotheses:

- The financial NPV per feddan of Sunt stands managed according to JMS is more attractive than that of stands managed according to FMS.
• The introduced changes in basic production assumptions affect profitability of A. nilotica stands, however, in different magnitudes and directions.

• The financial NPV per feddan of Sunt stands under present management is lower than that obtainable at financial rotation in each of the prescribed management strategies.

Chapter two: Literature review

2.1 Conceptual framework:

2.1.1 The concept of forest, land and capital values:

In the simplest case the capital value (L) of a piece of land is derived from the present worth of the annual rents (net money yield) which the owner expects to obtain (Gane, 1968). The present value of a repeated cash flow for some specified future period is called its capitalized value (Price, 1989). Each rent payment, worth R, in (n) years time, when discounted at an interest rate of r, has a present value of \( \frac{R}{(1+r)^n} \); the value of the land is obtained by adding up the stream of such present values in successive years to infinity;

\[
L = R + \frac{R}{(1+r)} + \frac{R}{(1+r)^2} + \frac{R}{(1+r)^3} + \cdots + \frac{R}{(1+r)^n}
\]

This may be written more concisely as;

\[
L = \sum_{n=0}^{\infty} \frac{R}{(1+r)^n}
\]  

(1)

and summed to give

\[
L = \frac{R}{r}
\]  

(2)

This formula is applicable to land in agricultural use which produces a harvest every year. It is more complicated to deal with land used for forestry, when, unless the forest has achieved the perfect state of normality like the model, the forest rent is bound to vary from year to year. At
some times there may be no mature timber to cut and at others the receipts from sales may be very large; similarly, costs of replanting will fluctuate. Therefore, the value formula must be rewritten:

\[ L = R_0 + \frac{R_1}{(1+r)} + \frac{R_2}{(1+r)^2} + \frac{R_3}{(1+r)^3} + \ldots + \frac{R_\infty}{(1+r)^\infty} \]

or

\[ L = \sum_{n=0}^{\infty} \frac{R_n}{(1+r)^n} \quad (3) \]

Alternatively, the forest rent, R, can be broken down into its components, S (sales) and C (costs) so that the formulae becomes:

\[ L = \sum_{n=0}^{\infty} \frac{S_n - C_n}{(1+r)^n} \quad (4) \]

Or what amounts to the same thing;

\[ L = \sum_{n=0}^{\infty} \frac{S_n}{(1+r)^n} - \sum_{n=0}^{\infty} \frac{C_n}{(1+r)^n} \quad (4) \]

The land value is simply the present worth of the receipts stream less the present worth of the costs stream (Gane, 1968).

### 2.1.2 Faustmann and yield management systems:

For the calculation of the value which forest land and immature stands possess for forestry, Faustmann (1849) distinguished between intermittent and sustained yield management. He establishes formulae for forest land which is bare of trees, and land currently carrying a stand.

For each case the formulae of forest (land) rent, bare (forest) land value and timber (or stand) value are established as applicable. Since the forest consists of partly the land, partly the
different stands, the value of the entire forest must be equal to their combined value (Ohlin, 1921).

Intermittent yield management is the case in which the whole area is successively felled and planted to create an even-aged stand. Formulae for forest land which is bare of trees under this system are presented in equations (5) and (6).

a. Forest (land) rent formula:

\[
R = \frac{i}{(1 + i)^u - 1} \left[ E + rD - C(1 + i)^u \right] - A
\]

where:

- \( R \) = annual land rent,
- \( i \) = interest rate per cent per annum,
- \( u \) = rotation length,
- \( E \) = the cash value of the final yield,
- \( D \) = the value of yield from thinnings during the rotation,
- \( rD \) = the value of “\( D \)” compounded to the end of the rotation,
- \( C \) = plantation costs necessary at the start of the rotation,
- \( A \) = annual expenditure for administration, protection, etc.'

b. Bare (forest) land formula:
From the forest land rent formula it is easy to find the value of the bare forest land \( B \) by simple capitalization of the annual forest land rent.

\[
B = \frac{R}{i} = \frac{E + rD - C(1 + i)^u}{(1 + i)^u - 1} - \frac{A_i}{i} \quad (6)
\]

This formula refers to a single unit area. If the number of acres is called \( F \), then the total land rent = \( R \times F \), and the land value = \( B \times F \). Formulae for forest land which is currently carrying a stand under this system are presented in equations (7), (8), (9) and (10).

a. Formula for the stand value:

The stand value \( H \) is formed by the capital value at the end of the \( n \)th year obtained from the annual land rent \( R \), the annual expenditure for administration, etc. \( A \), and the plantation costs \( C \).

\[
H = (E + rD)\frac{(1 + i)^n - 1}{(1 + i)^u - 1} + C\frac{(1 + i)^u - (1 + i)^n}{(1 + i)^u - 1} \quad (7)
\]

if thinnings have already taken place, then a part of the land rent has been drawn in them; its capital value at stand age \( n \) should therefore be deducted from the value of \( H \). instead of this, …, greater conformity with the previous and following formulae can be achieved by deducting the thinnings still to come in the rest of the first rotation compounded to the end of the rotation \( (= r'D' \) from the total thinnings, also compounded to the end \( (= rD) \), discounting the difference \( (= rD - r'D') \) to the present

\[
\frac{rD - r'D'}{(1 + i)^{u-n}}
\]

and finally deducting this from the value of \( H \).
Thus

\[
H = (E + rD) \left[ \frac{(1+i)^n - 1}{(1+i)^u - 1} \right] + \frac{C[(1+i)^n - (1+i)^u]}{(1+i)^u - 1} - \frac{rD - r'D'}{(1+i)^u-n} \quad (8)
\]

This is the most general form of the formula for the stand value of fully stocked stands.

b. Bare (forest) land formula:

Is equal to B in equation (6) above. The difference between the capital values of all the incomes and expenditures, which occur until infinity in a forest, gives the value of the forest. The forest value (W) comprises the land value (B) and the stand value (H), viz. \( W = B + H \).

c. The formula of forest value (W):

\[
W = \frac{E(1+i)^n + rD(1+i)^{n-u} - C(1+i)^n}{(1+i)^u - 1} + \frac{r'D'}{(1+i)^u-n} - \frac{A}{1} \quad (9)
\]

where: \( W = \) forest value

However, \( H = W - B \);

\[
H = (E + rD) \left[ \frac{(1+i)^n - 1}{(1+i)^u - 1} \right] + \frac{C[(1+i)^n - (1+i)^u]}{(1+i)^u - 1} - \frac{rD - r'D'}{(1+i)^u-n} \quad (10)
\]

The land value remains the same, whether the area carries a stand or not, whatever the age of stand, and no matter whether it is fully stocked or abnormal; the difference (in the value of the forest) is attributable solely to differences in the stand value.
In the strictest type of *Sustained yield management* annual coupes occur, equal in number to the number of years in the rotation and stocked with stands of all ages from the youngest to the oldest. Each year a single unit is felled and re-planted. Formulae for forest land which is currently carrying a stand under this system are presented in equations (11) to (17).

a. Formula of the forest value:

Land value in sustained management is equal to that in intermittent management. If the annual yield is $E$, and the annual plantation and administration costs etc, are $C$ and $uA$ respectively, then the sustained annual net yield $= E-C-uA$. By capitalization of this income, as a perpetual equal rent, one finds the economic value of a forest in normal sustained management:

$$ W' = \frac{E-C-uA}{i} \quad (11) $$

b. Formula of stand and land values in sustained management taking accounts of the thinning yields.

In sustained management the same thinnings occur annually as are made during the whole rotation in an intermittently managed stand; the annual yield in that case is therefore $E + D$, and so the forest value is:

$$ W' = \frac{E+D-C-uA}{i} \quad (12) $$
The full land value in intermittent management is shown in equation (6), therefore in sustained management, assuming a normal forest conditions and a forest area which is \((u)\) times greater than the area under intermittent management

\[
B' = u \times B = \frac{u \left[ E + rD - C(1 + i)^u \right]}{(1 + i)^u - 1} - \frac{uA} {i} \quad (13)
\]

If there are no trees on the land, the forest value will coincide with the land value and can be calculated from the formula. But at other times, when trees are present, the forest value obviously exceeds the land value; the difference represents the value of the timber crop (Gane, 1968). In his solution for sustained forest management Von Gehren (in: Gane, 1968) indicates that: “the difference, or the net income, is the forest rent which can be capitalized to give the forest value. … He pointed out that forest value is not the same thing as the land value. The annual yield or forest rent is derived from two sources. Two kinds of capital must be present – growing stock and land capital- and to find the value of the latter it is necessary, first, to calculate the value of the growing stock and then to deduct this from the forest value. The difference between forest value and land value gives the value of the growing stock or stand value,

\[
H' = W' - B' = \frac{E + rD - C - uA}{i} - \frac{u(E + rD - C(1 + i)^u)}{(1 + i)^u - 1} + \frac{uA} {i} \quad (14)
\]

\[
H' = \frac{uC(1 + i)^u - E - rD}{(1 + i)^u - 1} + \frac{E + rD - C}{i} \quad (14)
\]

Finally, if one takes the size of each intermittently managed area as a unit of area, then these expressions become:

\[
W = \frac{E + D - C - A}{ui} \quad (15)
\]
2.1.3 Opportunity cost of factors of production employed in timber production:

Since most courses of action are selected from a range of alternatives, the decision to adopt one course of action means that others are rejected. The cost of the chosen course may, therefore, be looked upon as the loss sustained by foregoing the opportunity offered by the next best alternative. Opportunity cost is the revenue (or benefit) forgone when a factor of production is withdrawn or withheld from an alternative course of action (Price, 1989). Opportunity cost is defined as being equal to the net benefit, which would have resulted if this next best alternative had been undertaken. If a resource has no alternative opportunities for employment, it has no “opportunity cost” and therefore society sacrifices nothing from its employment in the single available activity (Pearse, 1967).

*Opportunity cost of forest land employed in timber production:*

The meaning and function of the cost (rent) of the land has been much confused in forestry literature. Most of the confusion has resulted from the contention that as long as forest land is useable for no purpose other than growing trees, it has no opportunity cost; there is no sacrifice in terms of alternatives foregone. And hence it is inappropriate to apply a cost to the land. This argument is basically incorrect. A forest owner always has an alternative to holding his land under the present crop of trees, namely to cut the trees and (perhaps) begin a new crop (Pearse, 1967). There are at least three independently sufficient reasons, however, for including the land in...
rent variables. The first is that the magnitude of the land rent depends upon the economic circumstances of each case; to assume it is zero involves the assumption that land is worthless. Secondly, the significance of the land value in affecting the calculated rotation length depends not only on its magnitude but also on the slope of the incremental cost function relative to that of the incremental value function. In other words, the importance of a given value of land rent depends upon the relative slopes of the incremental cost and value curves, and these slopes will be different for each set of conditions. Finally, maximizing this return involves maximizing the return to the fixed factor. Since the fixed factor in growing forests is the land, it is helpful if the analysis defines the optimum rotation clearly in terms of maximizing the return to the land (Pearse, 1967). The value of bare forest land is the discounted present net worth of the future crops of trees that can be grown on the land. Such a value can readily be converted into annual rent. The annual cost of holding land under the present crop of timber, therefore, is equal to the rent that would begin to accrue to the land if it was reduced to a bare condition through harvesting the present stand (Pearse, 1967).

*Opportunity cost of forest capital:*

The view that forestry holds an exceptional position within commerce and industry, and that its capital does not have to yield interest is completely inconsistent with the foundation of the land rent principle profitability requirements (Ohlin, 1921). In the absence of market imperfections, private entrepreneurs, like society as a whole, will gain most by allocating all resources to their highest use, and this will be done because they can earn higher returns in that use than in any other. Thus the implicit assumption in much of the forestry literature that certain factors are costless (such as land or capital in the form of trees) is incompatible with the concept of opportunity cost, which is basic to the whole of economic theory. Since capital is not unlimited, it cannot legitimately be considered free. There is always an alternative use of capital which will
yield a return. The return on capital to any particular use is the rate of interest that could be obtained if the user directed it to its highest alternative use. The cost of holding an inventory of timber is therefore the interest charge on the value of the timber capital; and the appropriate rate of interest is the highest rate that the investor could earn (after appropriate allowance for risk and uncertainty) on capital investment elsewhere (Pearse, 1967).

2.1.4 Criteria for estimation of optimum rotation length:

Even-aged stands have a definite beginning and end in time. The total length of the growth period from stand establishment to final harvest is referred to as the rotation (Clutter, 1983). Osmaston (1968) identifies six classes of rotation. The rotation that coincides with the natural lease of life of species on a given site (physical rotation); the rotation through which a species retains satisfactory vigor of growth and reproduction on a given site (silvicultural rotation); the rotation under which a species yields the most material of a specified size or specification for a special use (the technical rotation); the rotation that yields the greatest annual quantity of material (the rotation of the greatest volume production); the rotation that yields the highest average net income. (The rotation of the highest income, or the rotation is also called the rotation of the highest forest rental); and the rotation that is determined by financial considerations (the financial rotation). Sinden (1964) defines financial rotation as the age at which net discounted revenue ($NDR$) per £1 total invested capital is at a maximum.

Rotation age is thought by many to be the single most important decision affecting timber management (Leuschner, 1984). The meaning of optimal rotation depends on objectives (Price, 1989). The correct criterion to use depends on the management objectives. The landowner must first choose the management objective and then the criterion that maximizes it (Clutter, 1983). An optimal forest rotation criterion should maximize net economic benefits to either society or the private forest owner. Other goals may be to maximize personal or social utility or maximize
physical (either market or non-market) benefits. These goals may be useful for various purposes, but net benefit maximization allows for clear comparison of criteria and has been the general (though often unstated) goal used in the literature (Newman, 1988).

There are two distinct approaches to combine volume growth pattern, crop prize-size relationship, trends in ‘real’ price-size relationship, trends in ‘real’ price of timber, discount rate, value of land, climatic and other risks to crop survival or growth factors in assessing optimal rotation (Price, 1989). First, the “total” approach aggregates predicted costs and revenues of various rotations and select the rotation of highest $NPV$, $IRR$, forest rent, etc. This approach is normal in planning horizon. Second, the “incremental” (or less accurately ‘marginal’) approach regards extension of rotation as an investment decision: by leaving the crop standing, one effectively reinvests its current sale value in order to realize greater value in future. One may either compare the $NPV$ of the crop kept for one or a few more years with its current value, or divide the rate of value increase by the current value; this later figure, representing the current rate of return on the crop, is called the indicating percent. The “total” approach sets the norm for rotation length. However, there are circumstances where the method is inappropriate, and the incremental method proves valuable. The incremental approach is particularly useful in day-to-day decision making (Price, 1989).

2.2.4.1 The total approach:

Newman (1988) describes six criteria used for the determination of rotation length: Maximization of growth yield, Maximization of annual yield, Maximization of discounted net revenues from a single rotation, Maximization of discounted net revenues from an infinite series of like rotations, Maximization of annual net revenues, and maximization of the rate of growth of capital. Leuschner (1984) presents Money Yield Table and Land Expectation Value as additional
criteria of rotation length determination. De Rocher and Walker (1994) further add financial maturity as a method used in discerning the optimal investment strategy. Sinden (1964) promotes the use of production possibility curves and iso-revenue lines for rotation determination.

Maximization of gross yield: The Maximization of gross yield (MGY) criterion has no present theoretical support. It is an outgrowth of the mercantilist concept of management, in which a country’s economic policy was guided by the desire to maintain as large a stock of precious metals as possible. Maximum physical yields were desired to minimize importing of wood and spending of gold. It implicitly assumes a zero interest rate and zero costs. Prices have no effect on the optimal formulation.

The rotation is optimal when the value of the marginal product (VMP) equals price of the marginal physical product (MPP) or more simply since price is constant, when the marginal physical product alone is equal to 0. This criterion is unacceptable because it ignores all costs involved in growing the stand; interest costs in holding the timber, and treats the land as if it had no value. It fails to achieve its intended goal of maximum total wood production because the annual production from this model is less than the maximum average production (Newman, 1988).

Maximization of Annual yield: It is also known as the Mean Annual Increment (MAI) (Clutter, 1983), or Culmination of Mean Annual Increment (CMAI) or the biologically maximum sustained yield (MSY) (Newman, 1988). This criterion produces the greatest total physical product from a site permanently managed for forestry. It maximizes the average annual physical yield per acre. The total production on the long-term basis is greater than that of MGY because MSY implicitly assumes that the site will continue to produce trees after harvest and thus
contribute to the gross yield. It, like MGY, assumes zero costs and interest rates. At the optimum, the marginal growth rate is equal to the average growth rate (Newman, 1988). Wood yield is maximized over perpetual rotations if the stands are cut at the age where MAI reaches a maximum, often called the culmination of MAI, rather than at the age where wood yield is maximum (Leuschner, 1984). Rotations based on the culmination of mean annual increment, generally decrease as site quality increases (De Rocher and Walker, 1994). The MAI is the total volume per acre divided by the age of the stand at that time, or

\[
\text{MAI}_A = \frac{Y_A}{A} \quad (18)
\]

Where: MAI = mean annual increment, A = the stand age, Y = yield, or volume of wood that will be harvested at age A.

The MAI characteristics are: First, it does not directly consider the value of the products produced. The criterion is insensitive to the difference in products prices and the decision to grow a particular product is made independent of the criterion. Second, it does not take into account neither direct production costs nor the time value of money. Third, it is generally popular with public agencies. Finally, the MAI criterion is a good first approximation for rotation determination because it reflects the forest's physical production possibilities (Leuschner, 1984).

The problems with this method are that, again, costs and interest charges are ignored. Since price cancels out of the optimal solution, the optimal rotation is unaffected by changes in market conditions (Newman, 1988).

The MAI rotation also depends on the site quality. Generally the poorer the site, the longer it takes to grow the trees and the longer the rotation age. The unit of volumetric measurement also affects the rotation age for any particular stand. The maximum MAI rotation in cubic feet is shorter than for cords, which is shorter than that for board feet (Leuschner, 1984).
Maximization of discounted net revenues from a single rotation: The model is often simply called the present net worth (PNW) model (Newman, 1988) and can have several names including net present value and discounted cash flow (Leuschner, 1984). As usually calculated, present net worth calculations consider income from only one rotation (Gregory, 1972). The criterion assumes that the owner will maximize the PNW of the forest investment but does not account for future uses of the land when the rotation is completed. The use of net present value in practice necessitates simplifying the problem and making assumptions (Leech, 1993). The implied objective of the PNW criterion is the maximization of the present value of future cash flows. It considers all future costs and revenues as well as the time value of money (Leuschner, 1984).

The PNW is interpreted as the present value of the investment's gain or loss at the specified interest rate. It shows the present value of how much is leftover after the investor’s money has earned the specified interest rate. The present value of costs could be increased by the amount of the PNW, thereby earning exactly the stated interest rate. The PNW will indicate how much one can spend on a cost category and still earn the desired interest rate if that cost is left out of the PNW calculation and all others are included (Leuschner, 1984).

Maximization of discounted net revenues from an infinite series of like rotations: The formulation was derived first by Faustmann (1849) and later by Pressler, and finally by Ohlin (Lofgren in: Newman, 1988). Foresters know it by such terms as “soil rent”, “soil expectation value” (SEV), or "forester’s rotation" (Kant, 2003), or “land expectation value (LEV)” (Newman, 1988), or willingness to pay for land (WPL) (Klemperer, 1996). The later states that the notation $WPL_\infty$ is more descriptive and also allows distinction between an infinite series of rotation and 1 rotation followed by sale. The WPL is the net present value designed for bare
forestland – the present value of future revenues minus the present value of future costs, calculating just before reforestation (Klemperer, 1996). Economists have favored the NPV criterion for its conceptual and theoretical superiority (Schallau and Wirth, 1980). It is the superior decision criterion of those presented for several reasons (Newman, 1988): It assumes that the site will stay in forest production in perpetuity so that there is an explicit awareness of the effect that present decisions have on future possibilities. It optimizes the use of all inputs according to their guiding market price and leaves any excess returns as a rent to the site. Calculating willingness to pay for land as $WPL_\infty$ assumes that the rotation-end land value is the calculated $WPL_\infty$ (Klemperer, 1996). Thus, unlike the PNW formulation, $WPL_\infty$ accounts for changes in stumpage price and unit silvicultural cost in computing the optimal rotation length (Newman, 1988). The optimal solution includes a separate term for the land rental charge. This value often is not large for long rotations, but its inclusion in the rotation determination is nonetheless necessary because it assigns a value to the opportunity cost of the land from delaying the harvest one period (Newman, 1988). The formula implies sustained periodic equal harvests (Pearse, 1967). Faustmann model assumes all relevant factors including prices, costs, interest rates, the basic growth function, and thus, the optimal rotation age, are unchanging through time (Newman et al., 1985). When applied to land, the method of management or forest rotation which provides the greatest soil expectation value is the most profitable from the owner’s point of view (Gane, 1968).

The formulation assumes that after a harvest is completed, the site will be immediately regenerated, and that this process will be continued into the infinite future. The resulting stream of net revenues is discounted back to the present. The inclusion of any fallow period will increase the rotation length (Leech, 1993). Since all the variables are fixed, the optimum rotation age will also be constant (heaps and Neher in: Newman, 1988). The formulation is:
Title: Economic evaluation of two management strategies of Acacia nilotica plantations grown for saw log production along the Blue Nile, south of Sennar Dam, Sudan.

\[ V = \max(T) \{ [pQ(T)e^{-rT} - wE](1 + e^{-rT} + e^{-r2T} + \ldots) \} \]

\[ = \max(T) / \left( pQ(T)e^{-rT} - wE \right) / (1 - e^{-rT}) \] \hspace{1cm} (19)

Where \( \max(T) \) denotes maximization of the expression with respect to \( T \), and \( V \) is the solution for \( WPL_{\infty} \).

Many forest owners change land use or sell land before or after harvest, or at least consider the option. A willingness to pay for bare land, assuming land sale after 1 rotation is expressed in equation 20 (Klemperer, 1996). \( WPL_{1} \) considers the market value of land at rotation end.

\[ WPL_{1} = \sum_{y=0}^{t} \frac{R_y}{(1+r)^y} - \sum_{y=0}^{t} \frac{C_y}{(1+r)^y} + \frac{L_y}{(1+r)^t} \] \hspace{1cm} (20)

Where:

\( WPL_{1} \) = willingness to pay for land, assuming land sale at end of one rotation, $/acre

\( R_y \) = revenue in year \( y \)

\( C_y \) = cost in year \( y \)

\( L_y \) = market value of land in year \( y \)

\( r \) = real interest rate, percent/100

\( t \) = rotation age (clear cutting)

\( y \) = an index for years from 0 to \( t \).

Faustmann (1849) initiated the notion of viewing the first and subsequent rotations as an infinite series of identical cash flows for each rotation starting with an initial establishment cost. This cash flow series is discounted to the present and becomes the objective function (Medema and Lyon, 1985). Clutter \textit{et al.} (1983) indicate that the basic formula for bare land value can be
written in several forms, all of which are algebraically equivalent. The most common forms for
the simple plant and clear-cut situation are:

\[ BLV_i = -R + \frac{SY_t - R}{(1+i)^t - 1} - \frac{T}{i} \]  (21)

and

\[ BLV_t = \frac{SY_t - R(1+i)^t}{(1+i)^t - 1} - \frac{T}{i} \]  (22)

Where;

- \( BLV_i \) = bare land value at discount rate \( i \)
- \( R \) = per acre regeneration cost
- \( S \) = per cunit stumpage price
- \( T \) = annual per acre ad valorem tax and administration cost
- \( Y \) = per acre yield in cunits at the end of the rotation
- \( i \) = inflation free interest rate

However, for management regimes that involve expenses at various times and incomes from
intermediate cuts, the bare land value can be calculated (Clutter et al., 1983) as:

\[ BLV_t = \frac{\sum_{j=0}^{t} (I_j - C_j) * (1+i)^{t-j}}{(1+i)^t - 1} \]  (23)

Where;

- \( BLV_i \) = bare land value at discount rate \( i \)
- \( I_j \) = Income in year \( j \)
- \( C_j \) = Cost in year \( j \)
- \( t \) = rotation age
- \( i \) = annual discount rate
Division by \([(1 + i)^t - 1]\) provides the discounted sum of the continuing series (Clutter, 1983).

Klemperer (1996), addressing the willingness to pay for land per unit area, ignoring taxes and assuming perpetual rotations presents the following equation:

\[
WPL_c = \frac{\sum_{y=0}^{t} R_y (1 + r)^{t-y} - \sum_{y=0}^{t} C_y (1 + r)^{t-y}}{(1 + r)^t - 1} + \frac{a - c}{r} \tag{24}
\]

Where:

- \(WPL_c\) = willingness to pay for land per unit area
- \(R_y\) = revenue in year \(y\), \$/unit area
- \(C_y\) = cost in year \(y\), \$/unit area
- \(t\) = rotation age
- \(y\) = an index for years from 0 to \(t\)
- \(r\) = real interest rate, percent/100
- \(a\) = equal annual revenue, \$/unit area
- \(c\) = equal annual cost, \$/unit area

assuming only the cash flows in the equation, \(WPL_c\) is the maximum an investor could pay for bare land and still earn the minimum acceptable rate of return \(r\).

The simplest form of soil expectation value (\(E\)) is:

\[
E = \frac{S}{(1 + i)^{t_m} - 1} \tag{25}
\]

where \(S\) is annual harvest value and \(t_m\) is each rotation period.
The site expectation value (E) is the maximum amount an investor can afford to pay for the bare land. It is the capitalized value of the expected future net returns from the land, valued when the land is bare at the beginning of first rotation. It is the opportunity cost of holding the standing forest, since the alternative to holding standing timber is to harvest it, thereby reducing the value of the property to E (Pearse, 1967). Equation (25) therefore provides us with an expression for the opportunity cost of holding the land under the present crop of trees. If the annual incremental change in the stumpage value (S) of the forest over time (t) is denoted as \( \Delta S \). The optimum rotation is indicated where the incremental revenue curve (\( \Delta S \)) intersects with the incremental cost curve (\( a + iS \)) i.e. \( \Delta S = a + iS \).

But for the purposes of determining the optimum rotation, we require the annual opportunity cost (a) of using the land. The annual equivalent of E is therefore required. The convention of a capital sum (E) into its annual equivalent (a) given an interest rate (i), is simply

\[
a = i \ast E \quad (26)
\]

and this (a) is precisely the annual opportunity cost of holding the land under trees (Pearse, 1967). Equation (25) can now be expressed in terms of the annual cost or value of the land by substituting for E, thus,

\[
a = \frac{iS}{(1+i)^m - 1} \quad (27)
\]

This is the Faustmann formula expressed in terms of the annual equivalent of the bare land value. Substituting the expression for the land value (a) from equation (27) in the equation \( \Delta S = a + iS \), we have
\[ \Delta S = \frac{iS}{1 + \frac{1}{(1 + 1)^{t_m} - 1}} \]  

(28)

this can be most readily solved in the form

\[ t_m = \log \frac{\Delta S - \log(\Delta S - iS)}{\log(1 + i)} \]  

(29)

Solution of this equation will yield the optimum economic rotation, which will, by definition, give the highest possible value of \( E \) and hence also to the highest possible value for \( a \). In other words, the optimum rotation maximizes the return to the fixed factor, land.

**Maximization of annual net revenues:** This criterion, also known as forest rent, was proposed, in part, to justify longer rotations than those prescribed by the soil rent criterion. It is meant to be used in a fully regulated forest – a forest where equal annual harvests are made and the land is immediately returned to timber production (Newman, 1988). It is the mean annual net revenue over the rotation (Price, 1989). At the optimum, the VMP equals the average annual net revenues. Both prices and costs affect the optimal rotation length (Newman, 1988). The forest rent criterion makes no distinction between revenues and costs occurring at different times.

Forest rent is defined as (Price, 1989)

\[ \sum_{t=0}^{T} R_t - \sum_{t=0}^{T} C_t \]  

(30)

The characteristics of forest rent criterion are: First, the implied management objective is maximization of average net revenue. Second, only the operating costs are included in the calculation. Neither the cost of land nor the time value of money is included (Leuschner, 1984). The forest rent criterion makes no distinction between revenues and costs occurring at different times.
times (Price, 1989). The exclusion of the time value of money and land cost precludes serious consideration of forest rent as a rotation criterion (Leuschner, 1984).

*Maximization of the rate of growth of capital:* Commonly known by such terms as “internal rate of return” (IRR) or “rate of return” (ROR) maximization (Newman, 1988). The implied management objective of this criterion is the maximization of the returns on investment (Leuschner, 1984). The criterion also has the same characteristics as the PNW criterion; inclusion of all costs and revenues, consideration of the time value of money, and a shorter rotation than that of MAI or other criteria (Leuschner, 1984). It assumes that capital, not land, is fixed and it returns all rents to the capital investment and maximizes the rate of return on that investment. It assumes that the returns can be reinvested at this maximal rate forever. The rotation length is optimal when the rate of growth is maximized. This is then the maximum rate of return of the IRR. If $i > r$, the IRR criterion will give a shorter rotation than the PNW criterion. If $i < r$, then no investment will be made as a negative PNW arises.

There are many conceptual problems with the use of this criterion. The primary problem is that maximizing IRR maximizes something besides the owner’s wealth. IRR maximization assumes that the amount of land available for forestry is infinite and that access to all capital markets is closed. Thus the owner will continue to invest all the returns from the original investment and never consume from the earnings (Newman, 1988). IRR cannot be calculated when there are no establishment costs to set equal to discounted revenues; the IRR of all rotations is infinite (Price, 1989). The IRR criterion is calculated for a single rotation and is based on the same cash flows as the PNW (Leuschner, 1984). IRR of successor crops is the same as that of the first crop (Price, 1989). Of the failing of the IRR criterion, particularly dangerous in the forestry context are the predilection of the IRR for purely exploitive land uses, and the inbuilt mechanism for belittling
large costs occurring late in a project’s life (Price, 1984). Like the PNW, this criterion results in a shorter rotation than that of MAI or other criteria (Leuschner, 1984). The maximization of return on investment is a widely accepted criterion; however, the maximization of IRR is not widely used for rotation determination (Leuschner, 1984).

**Land expectation value:** Land expectation value is defined as

\[
L_e = V_0 \times \frac{(1.0 + i)^n}{(1.0 + i)^n - 1.0} \tag{31}
\]

It is a special case of the PNW criterion due to four assumptions (Leuschner, 1984): first, the land value is zero; second, the land has no residual stand; third, the land will be forested in perpetuity; and fourth, the cash flows from the forest will be the same in perpetuity. The implied management objective is the maximization of the investment’s residual value when land cost is excluded. Stated differently, the criterion maximizes the capitalized land value. The criterion considers all costs and revenues except land cost, which is specifically excluded. However, the time value of money is considered. \(L_e\) maximization is an incomplete financial criterion for rotation age determination because land value is excluded from the costs (Leuschner, 1984). The difference between the PNW and the \(L_e\) criterion is that land cost and its subsequent sale is included in the PNW criterion and that the analysis is made for a single rotation.

Land expectation value is an income value of the investment. This income value is then compared to the market price of the land and the decision whether or not to buy is made (Leuschner, 1984). The land is not bought if market price is greater than \(L_e\) because the investor would then be earning less than the chosen interest rate and would have incurred an opportunity cost for the difference.
Money Yield Table: The implied management objective of the money yield table criterion is to maximize total revenue in a single rotation, but not over time. Also implied, if a constant price is used for calculating the criterion is maximization of the total yield in a single rotation. Neither production costs nor the time value of money are considered (Leuschner, 1984).

Production possibility curve and iso-revenue lines: Sinden (1964) introduces a principle to aid in the economic analysis of the rotation problem. The principle is designed to meet the arithmetic difficulty without the often desired recourse to a computer. He states: “The technique which is developed from this principle allows the marginal decisions on rotations to be made rapidly and to be based on the whole range of cost conditions, productivity classes of selected stands, and current product prices which are believed to be steady for the, say, five years”. He adapted a set of theoretical principles of production economics and developed ‘production-possibility curves’ and ‘iso-revenue lines’ to facilitate the marginal decision on rotation length. Further, he presents net discounted revenue per £1 as the criterion of financial success. The technique involves the use of three assumptions. First, the timber crop yields only two products- pulpwood (pw) and sawtimber size (st). Second, all of the pulpwood is sold at one price, and all of the sawtimber is sold at one price. Third, volume yields are normal. Finally, he stated, the identity which the optimum rotation must satisfy becomes, when the expression

\[
\frac{TPV_{pw}}{TC} + \frac{TPV_{st}}{TC}
\]

at definite product prices, is a maximum.

2.1.4.2 The incremental approach:
Howe (1979) indicates that just keeping the tree another year involves two types of costs: (1) The proceeds from cutting the tree are deferred and interest (earnings in alternative uses of those funds) on those proceeds is lost. (2) The land occupied by the tree is foreclosed to any alternative use and the income from that alternative use is foregone. The first item is simply the opportunity cost of the capital now tied up in the tree. The second item is called the “site expectation value”. It is the annual rent that such a piece of land could command that is foregone by letting the trees grow another year. A quick assessment of the benefits and costs associated with allowing the trees to grow another year then suggests the following rule for determining the optimal rotation (Howe, 1979): “allow the trees to continue growing as long as the annual increase in the stumpage value exceeds the interest forgone on the stumpage value plus the rental value of newly planted land”. Ohlin (1921) verifies that the yearly increment of a stand should be at least of the same proportion as the interest on the cutting value and the land value taken together, in order to make it profitable to let the stand grow.

The holding value\(^1\) is the owner's net present value of future cash flows from an asset. In timber production it is the net present value of holding the forest and selling the land and timber at the *optimal rotation age* \(t\). As long as the owner’s holding value exceeds the liquidation value (potential timber clear-cutting revenue plus land value), it is worthwhile to hold the forest and not clear-cut. When the forest holding value exceeds the liquidation value, the timber is said to be financially immature. The optimal rotation age is where holding value equals liquidation value (Klemperer, 1996).

\(^1\) Mathematically it is represented (Klemperer, 1996) as:

\[
\text{Holding value at age } y = \frac{H_t + L_t}{(1+r)^{t-y}} + \frac{(a-c)[1-(1+r)^{-(t-y)}]}{r}
\]

where; \(H_t\) = clear cutting revenue at rotation age \(t\), S/acre; \(L_t\) = market value of land in year \(t\), S/acre; \(a\) = equal annual revenues, S/acre; \(c\) = equal annual costs, S/acre; \(y\) = an index for years; \(t\) = rotation age in years; \(r\) = real discount rate, percent/100.
The optimum economic rotation occurs at that age where the instantaneous value growth rate is equal to the instantaneous opportunity cost incurred by delaying the harvest (Clutter et al., 1983). Since time is an input to the production of timber, at the optimal rotation age the marginal revenue product (MRP) of letting the stand grow one more year must equal the marginal input cost (MIC) of doing so (Chang, 1982). Or alternatively, the stand should be harvested at age where the marginal benefits of not harvesting the stand equal the marginal cost. This is often referred to as the Fisher (1930) solution (Medema and Lyon, 1985).

The rotation age is optimal when the VMP from letting the stand grow one more period is equal to the cost of holding the growing stock (the amount of interest that could be earned by harvesting the stand and investing the returns at the interest rate for one period) plus the cost of holding the land (the interest costs of delaying revenues from future harvests one period). As the planting cost increase or the price decreases, the rotation length increases (Newman, 1988).

2.1.5 The effect of change in economic variables on optimum rotation length:

The cost and price of timber:

Chang (1983) studied the simplest case of the relationship between rotation age, management intensity, and the economic factors of timber production, namely, site preparation cost, planting cost, stumpage price and interest rate. The simplest case, he pointed, is of a plantation with the management intensity narrowly interpreted as the planting density. An increase in site preparation cost would always lengthen the rotation. He concluded that with the exception of site preparation cost changes in other parameters could always lead to the possibility of uncertain results.
Newman et al. (1985) investigating the optimal forest rotation with evolving prices, argue that there are two impacts; the impact of rising relative prices and the impact of the change in price level. Using a theoretical model involving only a single modification of those general assumptions for the static Faustmann analysis, i.e. real price, rather than being constant, is a function of time. All other factors including real costs, discount rates, and the basic growth function of the stand remains constant over time. Costs occur only during regeneration and the price, net of harvesting cost, is for a single product with no quality variation. They considered four obvious cases of increasing prices. The simplest case of, there are no price increases (i.e., \( w = 0 \)), where "\( w \)" is price increase at a constant exponential rate (i.e., \( P'(T_i)/P (T_i) = w \)). This is the static Faustmann model. All factors are constant and it can be shown that all the rotation lengths are identical (Heaps and Neher in: Newman et al., 1985). The second case which examines the situation where the constant rate of price increase is less than, but very near to, the discount rate, gives the result that \( h_i > h_{i+1} \) for all rotations (where \( h_i \) is the rotation length of the timber stand in period \( i \)). Allowing \( w \) to approach \( r \), gives the steady-state rotation result that the ratio of marginal product to total product is equal to the inverse of steady-state rotation length. This rotation length, known by foresters as the maximum sustained yield rotation (MSY), produces the greatest annual physical yield on a site. Optimum economic rotations potentially longer than MSY have generally been proposed only in cases of a relatively high cost to price ratio and low interest rates or where the amenity value associated with a growing timber stand increases as the stand itself ages (Hartman; Bowes; in Newman (1985). Where the value gains are great enough, harvests might be delayed indefinitely. In their case, Newman et al., indicates that earlier rotations are optimally longer than the MSY in order to put off the payment of relatively more expensive regeneration costs. Succeeding rotations approach the MSY from above as the relative effect of the regeneration costs diminish. The final case considers a rate of price increase greater
than zero but less than the discount rate \((0 < w < r)\). As in the second case, succeeding rotation lengths continually decrease over time.

Chang (1984) examined the impact of changes in regeneration cost \((C)\), interest rate \((r)\), and stumpage price level \(P(t)\) on the optimal rotation. He concluded that when regeneration cost goes up, the new optimal rotation is longer than the original one. When interest rate goes up and when price of timber increases, the new optimum rotation age is shorter than the original one. It is well known that an increase in stumpage price will lead to a decrease in the optimal rotation (Binkley, 1987).

Binkley (1987) raised the question of when is the optimal economic rotation longer than the rotation of maximum sustained yield. He challenged the argument that the optimal economic rotation approaches the culmination of mean annual increment only as the discount rate approaches zero. He concludes that this conclusion is valid only if regeneration and management costs are ignored. Once even a very simple production cost formulation is introduced into the problem, economic rotations may equal, or exceed the maximum sustained yield rotation. He further concludes that for economic rotations to be greater than the MSY rotation, the interest rate must be less than the inverse of the MSY rotation. For comparatively slow growing species, such as Douglas fir, the MSY rotation will be in the order of 100 years. On the other hand, fast growing species e.g. *Pinus patula*, may reach the culmination of mean annual increment in less than 20 years. In such situations, the optimal economic rotations might be greater than MSY under a wide range of cost and price parameters. In practice, economic rotations exceeding MSY rotations are more likely to arise with fast than with slow growing species.
Most authors who have supported Faustmann's proposition have either explicitly or implicitly, assumed the existence of a purely competitive stumpage market (Nautiyal and Fowler, 1980). In a pioneer writing because it considered market imperfections, Nautiyal and Fowler (1980) examined the effects of monopolistic forest ownership on the optimal rotation. They examined maximization of net present worth from the point of view of an owner of a relatively small forest area (private soil expectation value of atomistic owner) and large forest owners, who presumably face a downward sloping demand curve for stumpage, for both regulated and unregulated forests. They stress that the conclusion that forests are best managed if their present worth is maximized, must be clearly quantified by the necessity of pure competition in the stumpage market. However, their main conclusions are:

(a) In the absence of such competition, the socially optimum rotation has been shown to be longer than that which a monopolistic, private owner would select. This is confirmed by McConnell and Phipps (1984) who state that the application of Faustmann's formula results in a rotation that is longer than the socially optimum rotation.

(b) But, it is shorter than the rotation that would be obtained by assumption of pure competition when it does not exist. The distortion caused by monopoly occurs because an increase in rotation raises the final harvest output and reduces the price. In order to maximize the private present net worth of returns the monopolist therefore restricts output by employing less of the input under consideration - time.
A monopolistic forest owner will choose a steady-state rotation period shorter than the competitively selected rotation period in order to restrict the annual harvest volume (Anderson, 1981).

(c) The monopolistic optimal rotation for a single large forest owner is shorter than the atomistic optimal rotation. McConnell and Phipps demonstrate that it is less clear that the relationship between the monopolist's rotation and society's rotation is determined by the direction of change in the price elasticity of demand. They further point out correctly that the socially optimum rotation will not be shorter than the monopolistic rotation when the demand function is either isoelastic or the absolute value of the price elasticity of demand increases with large volumes of wood in the market. Nautiyal and Fowler (1980) further conclude that the monopolistic departures from the atomistic optimal rotation are much smaller in a regulated forest (the classical fully regulated forest but one that begins with bare land) than in the unregulated case.

Price (1989) indicates that higher timber prices shorten rotations, possibly to less than the rotation of maximum volume production, while silvicultural factors like delay of regeneration, which reduces profit, prolong rotation. He further adds ‘if there is a technically optimal tree size, mean tree price will surge upward as most of the crop moves into this category, and the optimal rotation is likely to come soon after. By contrast, if there are technical limits to the size of tree that can be harvested or processed, a dip in mean tree price signals that the optimal rotation has been exceeded’. If forest land is rented temporarily, short rotations curtail rent payments. .. the higher the rental the shorter the rotation. If the land is owned, but could be sold for another purpose, the higher its price, the greater is the loss by postponing sale. If the land is dedicated to forestry, shorter rotations allow a succession crop to utilize the land earlier (Price, 1989).
Klemperer (1996) concludes that compared to a constant stumpage price per unit volume, an increasing stumpage price over time will raise the forest value growth percent\(^2\) curve and lengthen the optimal rotation.

**Taxes:**

Currently, the major types of taxes that can be imposed on a forest property may be divided into annual property taxes and harvest taxes. The former includes the “unmodified property tax” and the “site value tax”. Every year, the “unmodified property tax” takes a percentage of the value of the land plus the value of the trees, and the “site value tax” takes a percentage of the value of the land only. Still a third type of property tax, called the timber tax, takes a percentage of the value of the trees only every year. Harvest taxes include yield taxes and severance taxes. At the time of harvest, the “yield tax” takes a percentage of the stumpage value of timber and the “severance tax” imposes a charge per unit of timber volume harvested (Chang, 1982). The desirability of one of the most common principles of taxation; that taxes should not interfere with the most efficient economic use of a resource (Pearse, 1967). With the optimal rotation period described, an efficient tax (or a “neutral” tax) is one that will not induce a deviation from this optimum. The effects of the major forestry taxes on optimal rotation length are reviewed hereunder.

A property tax, which each year taxes a percentage of the land and timber value, generally causes a shorter rotation as it is similar in effect to an increase in the interest rate (Pearse, 1967; Chang, 1983; Newman, 1988) and reduces planting density (Chang, 1983), as well. The amount of rent

\[ \text{Annual forest value growth } \% = \frac{(H_{y+1} + L_{y+1})(H_y + L_y) - (a - c)}{H_y + L_y} \]

Where: \( H_y \) = potential net clear-cutting revenue in year \( y \), \$/acre; \( L_y \) = market value of land in year \( y \), excluding crops \$/acre; \( a \) = annual revenue \$/acre; \( c \) = annual cost \$/acre
that accrues to the land will be reduced as a result of the sub-optimum rotation, and the site expectation value of the site for a private owner will be reduced in proportion (Pearse, 1967).

The land expectation value under an unmodified property tax can be simplified as (Chang, 1982):

\[ LEV_{upt} = \left( \frac{r + y}{r + x} \right) \left[ \frac{(1 + \alpha) V(t) - C e^{(r+y)t}}{e^{(r+y)t} - 1} \right] \]  

\[ = \left( \frac{r + y}{r + x} \right) \left[ \frac{(1 + \alpha) V(t) - C}{e^{(r+y)t} - 1} - C \right] \]  

where:

- \( LEV_{upt} \) = Land expectation value under unmodified property tax;
- \( r \) = interest rate (in decimals);
- \( t \) = rotation age
- \( y \) = annual property tax rate (in decimals) on the assessed value of the tree;
- \( x \) = annual property tax rate (in decimals) on the value of the land;
- \( \alpha \) = the tax-induced percentage increase in stumpage value;
- \( V(t) = P(t) Q(t) \) the pretax stumpage value of a t-year-old timber stand under any method of assessment;
- \( C \) = regeneration cost;

A site value tax, which each year taxes a percentage of the value of the land only, does not affect the optimal rotation (Pearse, 1967; Newman, 1988) because this tax only affects the
economic rents from the site (Newman, 1988). Clearly, the introduction of the site value tax would only cause a proportional decrease in the land expectation value for all planting densities and rotation ages. Whatever planting density and rotation age that would maximize the land expectation value before tax, would also maximize the land expectation value after site value tax (Chang, 1983). Thus, the owner’s previous optimal strategy of maximizing potential rents is unchanged. The rents are just lower (Newman, 1988) by the present worth of the infinite series of future equal annual tax payments (Pearse, 1967).

When the value of the trees is not taxed (i.e., \( y = 0 \)), land expectation value becomes equal to the formula for land expectation value under a site value tax (Chang, 1982):

\[
\text{LEV}_{\text{svt}} = \frac{r}{r + x} \left[ \frac{(1 + \infty) V(t) - C e^{rt}}{e^{rt} - 1} \right]
\]

(34)

A yield tax, which taxes a percentage of the realized yield from the harvest time, generally lengthens the rotation as its effects are similar to a reduction in stumpage price (Chang, 1983; Newman, 1988) and lower the planting density (Chang, 1983).

A severance tax, which imposes a charge per unit of timber volume harvested, behaves like a yield tax. If the price remains constant, regardless of stand age, then there is no difference between the two. If the price increases with stand age, then the tax’s effect is like a yield tax whose rate decreases with the age of the stand (Newman, 1988). A severance tax (or royalty) in the form of a percentage charge against the value of the timber harvested, does not disturb the optimum rotation, since all incremental costs and revenues are reduced in proportion and the indicated rotation will remain unchanged (Pearse, 1967).
When the value of the land is not taxed (i.e., $x = 0$), land expectation value becomes equal to the formula for land expectation value under a timber tax (Chang, 1982):

$$\text{LEV}_x = (1 + x) V(t) - C e^{\pi t} - \int_0^t y V(s) e^{\tau(1-s)} ds \quad (35)$$

$$\text{LEV}_x = \frac{(1 + x) V(t) - C e^{\pi t + y \tau}}{e^{\pi t + y \tau} - 1} \quad (36)$$

These results are modified somewhat if the taxes are fully capitalized or shifted forward onto higher valued stumpage (Newman, 1988). By modifying the tax rate, it appears that government policies will affect land management policies by lengthening or shortening the rotation age. Increasing taxes lowers the profits from managing land for timber and thus reduces the total timber acreage as economically marginal production areas are not viable and drop out of production. … Local municipalities, reliant on property tax to fund general activities and wanting to assure themselves some returns from their dwindling local forest resources, continually raised taxes on forest land and timber. These taxes augmented the desire to cut the timber by sawmill owners and probably increased the rate of exploitation. Worse for these communities, since the high tax rates made sustained yield management an ever less possible alternative, timber holdings were liquidated as cheaply as possible, with little thought given to the long-term effect on the land, and the owners move on to other areas.

**Thinning:**

Näslund (1969) discussed the principles for solving the problem of determining optimal rotation $T$ and various managerial activities such as thinning, simultaneously, with the aid of linear programming techniques. The problem, he outlined, is treated in three phases. First, expression of the present value of an infinite series of discounted future net revenues. Second, use of the
Maximum Principle in replacement theory to allow for thinning at discrete points in time. Finally, the simultaneous determination of the size and time of thinning and rotation. He concludes that: (a) with respect to optimum rotation, the forest shall be cut when the current income for having the forest one more year plus the increase in sale value equals the interest on the sales value and the soil rent. (b) Regarding thinning, if the present value of the increase in instantaneous revenues from thinning is greater than the present value of the decrease in final sales value due to thinning, then the thinning ought to be undertaken.

*Discount rate:*

A change in the interest rate will shift the interest charge on the stumpage value more than the land rent. The effect, therefore, of a change in the interest rate will always be to shift the point of equality between incremental revenue and cost in the opposite direction. A lower rate will always give increased relative weight to returns receivable in the more distant future (Pearse, 1967). Low discount rates usually lengthen rotation (Price, 1989) and increase the net present value of forest investments (Klemperer, 1996). Forest owners will clear-cut timber when the forest value growth percent drops below their minimum acceptable rate of return (MAR). Therefore, the higher the discount rate, the shorter the economically optimum rotation (Klemperer, 1996).

*Carbon sequestration:*

The inclusion of the positive externality generated by carbon sequestration increases rotation age with respect to traditional FPO (Faustmann-Preseeler-Ohlin) solutions (Romero et al., 1998).

**2.1.6 Extension of Faustmann model:**

*Changing future timber prices:*
Bare and Waggener (1980) examined the role of future timber prices expectation in determining both present and future forest land values and the relationship of price expectations to rate of return on investment. They presented the simplest situation of Faustmann formula and then relaxed the assumptions gradually in three other cases. The first involves the assumption that the future harvest value \( S_n \), all costs of management, and the discount rate remain constant in perpetuity. The per-acre net present value is written as:

\[
NPV = \frac{-c(1+i)^n - L_0(1+i)^n + L_n + S_n - a}{(1+i)^n - 1} \quad (37a)
\]

or in an equivalent form

\[
NPV = \frac{-C(1+i)^n + S_n - L_0 - \frac{a}{i}}{(1+i)^n - 1} \quad (37b)
\]

where

- \( c \) = reforestation costs/acre at time \( t = 0 \);
- \( a \) = annual costs/acre of taxes, administration, etc.
- \( L_0 \) = bare land value/acre at time \( t = 0 \);
- \( L_n \) = bare land value/acre at time \( t = n \)
- \( S_n \) = harvest value per acre at rotation age \( n \);
- \( i \) = real discount rate in decimal form
- \( n \) = rotation age;
- \( NPV \) = net present value of perpetual series of identical cash flows

The maximum amount, \( L_0 \), which we would be willing to spend to purchase an acre of bare land upon which continuous crops of timber will be grown in perpetuity. This is found by setting \( NPV \) in equation (37b) equal to zero and solving for \( L_0 \).

\[
L_0 = \frac{-c(1+i)^n + S_n - a}{(1+i)^n - 1} \quad (38)
\]
This is the familiar Faustmann (1849) formula where land is treated as a fixed factor of production and all economic rent is attributed to land.

The second case involves relaxation of the assumption of constant revenues over time while continuing to hold costs and technology constant. The specific assumption is that the harvest value of mature timber is expected to increase at a real rate of p percent in perpetuity. Under these conditions, equation (38) becomes

\[
L_0 = \frac{-c(1+i)^n}{(1+i)^n - 1} - \frac{a}{i} + S_n \left[ \frac{(1+p)^n}{(1+i)^n - (1+p)^n} \right]
\]  

(39)

Where \( S_n \) = the current harvest value/acre of rotation-aged timber.

The third case assumes costs and technology constant over time but allows harvest value to increase during the first rotation only. The present harvest value (\( S_n \)) is assumed to increase at an annual rate of p percent per year for \( n \) years and to remain constant thereafter. Accordingly:

\[
L_0 = \frac{-c(1+i)^n + S_n(1+p)^n}{(1+i)^n - 1} - \frac{a}{i}
\]  

(40)

The final case assumes a constant harvest value during the first rotation but with a perpetually increasing harvest value thereafter. Again all costs and technology are held constant. The formula becomes

\[
L_0 = \frac{-c(1+i)^n}{(1+i)^n - 1} - \frac{a}{i} + \frac{S_n}{(1+i)^n} \left[ 1 + \frac{(1+p)^n}{(1+i)^n - (1+p)^n} \right]
\]  

(41)

Bare and Waggener (1980) conclude that (a) expectations concerning the future harvest value play a crucial role in determining today’s bare land forest value (\( L_0 \)), (b) Land values will remain constant only if the harvest value is expected to remain constant or increase during first rotation only, (c) \( L_n \) is greater than \( L_0 \) if positive harvest value increases are anticipated beyond
the end of the first rotation, and (d) such future price expectations influencing $L_n$ are fully
capitalized into a higher present land value ($L_n$).

Kant (2003) indicates that as a result of evolution of forest management, the concept of sustained
yield has been replaced by the concept of sustainable forest management. He stresses the need
for extending the boundaries of forest economics, accordingly. The new forest management
paradigm has transformed forest management from timber management to forest ecosystem
management, from sustained timber yield management to sustainable forest management. The
basic elements of sustainable forest management are the maintenance and enhancement of forest
ecosystems and their contribution to global ecological cycles, the conservation of biodiversity,
soil and water resources, multiple benefits from forests and participatory forest management. He
concludes that the silviculture of the Faustmann formula continues to have a direct application
for plantation forestry, but not for sustainable forest management. He further adds that existing
forest economic models, including Faustmann’s formulation must be refined, and some new
economic theories and models must be developed to incorporate the features of sustainable forest
management (i.e. principles of ‘both and’, existence, relativity, uncertainty and
complementarities) as a foundation, and the economic principles, developed by evolutionary,
institutional, ecological economists and economists from other new streams of economics, will
be the useful tools to extend the boundaries.

Valuing forest services:

Strang (1983) considering the optimal harvesting strategy for a forest that provides value while
standing as well as when harvested. Standing timber, he points out, may provide wildlife habitat,
flood control, and recreational services which should be taken into account when the harvesting
decision is made. He stated that: ‘even though a finite, local maximum for optimal rotation
length may exist, a corner solution involving never cutting the forest may be the global maximum’. With respect to the status of forest land in question he further added: ‘previous treatments of the harvesting problem have taken the tract in question as initially bare. For many stands of timber, a climax or old growth forest initially occupies the land. The age at harvest in the first rotation, then may exceed that for subsequent harvesting cycles, this consideration leads to a different objective function to be maximized’. He shows that it might be preferable never to cut an old growth forest even if it is optimal eventually to harvest the same land if initially barren. This is due to the considerable standing values available from a climax forest. When standing trees yield non-monetary values like aesthetic benefits to land owners or recreationists, economically optimal rotations can be longer. In fact, if non-monetary benefits are large enough, the optimal rotation is infinitely long, as in wilderness areas (Klemperer, 1996).

The coppicing tree species:

Medema and Lyon (1985) develop an analytical methodology for the determination of financial rotation ages for coppicing tree species. The analysis is limited to the mechanics of determining financial rotation ages given a specific yield function, as opposed to the determination of an optimal rotation age. They examined the case of single and multiple rotations of the noncoppicing as well as the coppicing tree species. One cycle (the first crop, established from seeds or seedlings, through the last coppice) is a finite series. After the final coppice crop is harvested, a new cycle can be established. The procedure developed extends Faustmann's financial analysis to simultaneously determine both harvest ages and stand establishment frequency to maximize financial return for a given level of management intensity.

For the single cycle coppicing tree species the objective function to be maximized is:
Title: Economic evaluation of two management strategies of Acacia nilotica plantations grown for saw log production along the Blue Nile, south of Sennar Dam, Sudan.

\[ W = \sum_{r=0}^{n} \left[ g(t_r) \exp \left( -i \sum_{j=1}^{r} t_j \right) - C_r \left( \exp \left( -i \sum_{j=1}^{r} t_{j-1} \right) \right) \right] \]  \( (42) \)

Where

\( t_0 = 0; \)

\( W = \) the objective function for wealth maximization;

\( g(t) = \) Value at age \( t; \)

\( \exp = e \)

\( C = \) cost of establishment;

\( n = \) number of crops per cycle;

\( t = \) rotation age;

\( r = \) years in coppice rotation

\( i = \) rate of return

Unlike the non-coppicing case, this model formulation allows the rotation ages \( t \) to vary from crop to crop within a cycle. Differentiating, setting first order condition to equal zero, rearranging terms and simplifying the equation results in

\[ g'_n(t_n) = ig'_n(t_n) \]  \( (43a) \)

In general, to maximize \( W \) in the single cycle case equation \( 43b \) applies for \( m < n \).

\[ g'_m(t_m) = ig'_m(t_m) + i \sum_{r=m+1}^{n} \left[ g_r(t_r) - C_r \exp(it_r) \exp \left( -i \sum_{j=m+1}^{r} t_j \right) \right] \]  \( (43b) \)

They also treated the coppicing tree species case of multiple cycles. In determining the financial harvest ages for an infinite series of identical cycles for coppicing tree species with multiple cycles, the objective function to be maximized is:
Economic evaluation of two management strategies of Acacia nilotica plantations grown for saw log production along the Blue Nile, south of Sennar Dam, Sudan.


\[
W = \sum_{r=1}^{n} \left[ g_r(t_r) \exp \left( -i \sum_{j=1}^{r} t_j \right) - C_r \left( \exp \left( -i \sum_{j=1}^{r} t_{j-1} \right) \right) \right] \\
1 - \exp \left( -i \sum_{j=1}^{n} t_j \right) \tag{44}
\]

Or in general:

\[
g'_m(t_m) = ig_m(t_m) + \sum_{r=m+1}^{n} \left[ g_r(t_r) - C_r(\exp(it_r)) \right] \exp(-i \sum_{j=m+1}^{r} t_j) + i(\exp(-i \sum_{j=m+1}^{n} t_j))W \tag{45}
\]

for \( m < n \).

Determination of optimum cycle length in multiple cycle case requires solution for the optimal rotation ages and \( n \) simultaneously. With \( W_n \) and \( W_{n+1} \) represent the maximum wealth generated by \( n \) and \( (n+1) \) coppice crops per cycle, respectively or

\[
W_{n-1} = \frac{\sum_{r=1}^{n+1} \left[ g_r(t_r) \exp \left( -i \sum_{j=1}^{r} t_j \right) - C_r \left( \exp \left( -i \sum_{j=1}^{r} t_{j-1} \right) \right) \right]}{1 - \exp \left( -i \sum_{j=1}^{n+1} t_j \right)} \tag{46}
\]

With

\[
\Delta W = W_{n+1} - W_n \tag{47}
\]

Through a simple iterative search procedure, one can solve for the optimal \( n \). For example, starting from \( n=1 \) (only one crop per cycle), and allowing \( n \) to increase, the optimal \( n \) is achieved where \( \Delta W < 0 \) in going from \( n \) crops per cycle to \( n+1 \) crops per cycle.

Carbon sequestration:
Romero et. al., (1998) present an approach for the determination of optimum forest rotation ages when considering both timber production and carbon uptake. They indicate that the methods used to determine the optimal forest rotation age (e.g. Faustmann-Pressler-Ohlin (FPO) formula; Hartman, 1972) are not applicable when dealing with a measure of a public good (carbon stored in timber biomass), which is very difficult to transfer into monetary units. The proposed approach gives the optimal rotation age by the optimization of a utility function with two arguments (timber and carbon) over a production possibility frontier curve and, therefore, it differs considerably from earlier models. Within the setting of the model three optima (private, environmental, and social) may be derived. The age providing the maximum net present value ($W$) of timber, and maximum carbon ($S$) uptake are the private and environmental optimum, respectively. Social optimum is the point where the social welfare function $u(W, S)$ reaches a maximum.

The simplest expression of the FPO formula is the following (Romero et. al., 1998):

$$W(\text{NPV}) = \frac{P \cdot f(t) e^{-it}}{1 - e^{-it}} \quad (48)$$

Where:

$W = $ net present value associated with timber production

$P = $ timber price; $t = $ rotation age; $i = $ discount rate

Carbon uptake throughout the forest rotation can be measured in two different ways. Firstly, as total carbon sequestered, according to the following formula:

$$S = \gamma f(t) - \gamma \beta f(t) = \gamma (1 - \beta) f(t) \quad (49)$$
Where:

\( S = \) carbon uptake

\( \gamma = \) Proportion of carbon in timber biomass

\( \beta = \) Fraction of timber harvested whose carbon content is released into the atmosphere

Secondly, as carbon sequestered per year of forest rotation according to the following formula:

\[
S = \frac{\tilde{f}(t)}{t} - \gamma \beta \frac{\tilde{f}(t)}{t} = \gamma (1-\beta) \frac{\tilde{f}(t)}{t} \quad (50)
\]

By maximizing (50), the FPO rotation age \( t_F \), which provides a private optimum, is obtained. Similarly, by maximizing (51), or alternatively (52), the rotation age \( t_E \), which provides an environmental optimum, is obtained. For expression (51) the rotation age corresponds to the maximum possible timber output and for expression (52) the rotation age corresponds to the maximum sustainable yield for which the timber yield per year is maximized.

Romero et. al., (1998) find out that the presence of an externality, positive in this case, generates a divergence between the private and social optima. This divergence implies a Paretian inefficiency that can be removed by resorting to a Pigovian premium or subsidy to equalize both optima. A premium or subsidy of \( P_c \) monetary units per m\(^3\) of timber added to the growing stock is established. In the same way, a tax of \( \gamma P_c \) monetary units per ton of CO\(_2\) released into the atmosphere is established. The aggregate NPV is given by:

\[
\text{NPV} = \frac{P \tilde{f}(t) e^{-it} + \gamma P_c \int_0^t \tilde{f}(t) e^{-it} dt - \gamma P_c \beta \tilde{f}(t) e^{-it}}{1 - e^{-it}} \quad (51)
\]
The first term of (eq. 53) represents the timber benefits for the forest owner provided by the market; the second term represents carbon uptake benefits for the forest owner paid by society as a compensation for the positive externality generated by the forest. The third term represents the tax levied on the forest owner because of the release of a fraction $\beta$ of the stored carbon into the atmosphere when the final harvest is undertaken.

The FPO model introduced above captures the key elements of the problem. However, it does show clear inadequacies in a more general forestry context i.e. only includes the sales revenue derived from the final felling without including any additional payment or receipt, no consideration of financial aid given by the current European forest policy (Romero et. al., 1998). These problems can be redeemed by extending expression (50) to a general scenario. The general expression for the net present value is:

$$W(NPV) = \left[ R(t)e^{-it} + \sum_{\forall L} C_L e^{-iL} + P_m e^{-it_1} (e^{-i} - e^{-it_1}) + P_c e^{-it_2} (e^{-i} - e^{-it_2}) \right] (1-e^{-it})^{-1} \quad (52)$$

where:

- $R(t)$ = sales revenue derived from final felling
- $C_L$ = cash flow associated with the thinning operations take place in sub-periods $L_1$, $L_2$ … etc.
- $P_m$ = maintenance premium received during the first $t_1$ years of the plantation cycle
- $P_c$ = compensatory premium received during the first $t_2$ years of the plantation cycle
- $K_1$ = Subsidy to planting operations
- $K$ = planting costs
G = general annual management payments

\[ Y_S = \text{operating costs take place in sub-periods } S_1, S_1 \ldots \text{ etc.} \]

The above expression cannot be optimized by conventional calculus techniques. However, the corresponding optimum can be approximated by means of simple numerical computation exercise (Romero et. al., 1998). Expression (54) as well as the formulae for carbon uptake (51) and (52) were computerized and estimated for increasing values of (t). From these values a computation devise is obtained.

2.2 Establishment and management of *A. nilotica* plantations along the Blue Nile

2.2.1 History of management of the plantations along the Blue Nile

A beginning of forest reservation was made in 1906. In 1933 proposals were made for the reservation of the more important Sunt forests and by 1948 it was considered that the Forestry Department had acquired the main riverain land that could be put under forests. Proposals for the utilization of the forests were made at an early date, and about 1905 a sawmill was installed at Bunzuga and moved after one season to Saolel and was closed soon after. In 1933 a small sawmill was erected at Azaza to supply half-round sleepers to the contractors building Jebbel Aulia dam. A larger sawmill was opened at Launi in 1935 to produce SRS. During the Second World War heavy demands were made on the forests not only for the production of railway sleepers, but also for a number of other purposes. Pick helves and tent pegs were supplied in large quantities to the allied armies in Egypt, and sunt bark was used for camouflaging tents. This activity necessitated over-cutting in the forests. In general regeneration of the forests followed closely after felling and sunt continued to be the main species used. A simple cutting plan for the remaining natural forests was drawn up in 1946, and this was followed by the First Working Plan, prepared by G. A. Booth in 1948 to cover the period 1949/1958. A separate
working plan for the forests of Es Suki Range which were to be managed for firewood on a short rotation was drawn up at the same time. In 1955 it was decided that these forests also should be managed for timber production. The Second Working Plan was prepared by J K Jackson covering the period 1959/1968, and the Third Working Plan was prepared by A. Foggie covering the period 1969/1978. With the expiry of 1969/1978 working plan, Sunt forests of the Blue Nile were operated under provisional annual felling schedules. The Forest Management and Inventory Directorate of the FNC prepares the Working Plan for the period 1997-2006, currently in progress.

2.2.2 Silviculture and management of Acacia nilotica plantations:

Seeding and natural regeneration: The flush of seedlings, which regularly appears after the rains and floods within plantations, is from the accumulated seed of many years, whose seed coats are gradually weathering and allowing germination. This has a most important bearing on the use of natural regeneration (Foggie, 1968). Being a strong light demander the use of clear felling system is necessary. This will, however, destroy most of the seedlings already germinated and it is uncertain whether sufficient viable seeds will remain on the forest floor to furnish a second crop subsequent to the felling. Fortunately it is unnecessary to rely on natural regeneration as by treatment of the seed uniform germination can be induced and artificial regeneration by direct sowing can be practiced economically provided it is undertaken the first rains after sowing. Natural regeneration can therefore only be considered as an adjunct to the normal artificial regeneration (Foggie, 1968).

Sowing: The seed is sown either by broadcasting or in pits. Broadcasting may be done in two ways. The first is to scatter untreated seed in June before the flood, remembering that seed which lies under water after December will not produce a crop. The second is to broadcast treated seed within the edges of the flooded area as the water recedes. This is only successful if the area sown
dries out within seven days. It is the method generally used on flooded ground as it is cheaper than pit sowing. Pit sowing is the method used on the higher contours and on un-flooded grounds. Shallow pits are made at a spacing of 2m by 2m by a turia, and 6 seeds sown in each pit; the seeds are then lightly covered with soil (Jackson, 1959). The pits being dug, the soil worked up and replaced in the pit and 5-10 treated seeds sown and lightly covered. In areas, which are regularly flooded, pit sowing may not be possible before the water is on the surface. Such areas may be broadcast as the water is appearing using untreated seed (Foggie, 1968).

**Beating up** of sown areas should only be undertaken where there are failures over patches. It is not worth re-sowing individual failing pits or where establishment overall is 80% or more. Re-sowing should be carried out either in September or early October of the year of sowing or in June / July of the following year (Foggie, 1968).

**Weeding**: Sunt is sensitive to weed competition, and through weeding is necessary in the first two years, especially in Gerf land or areas infested with addar (Jackson, 1959). If labor and funds are available weeding can be treated out with advantage one a month during the rainy season, August, September, October and a last weeding in November, but this is generally not possible and two weedings in late August and early October must suffice (Foggie, 1968).

**Singling**: Singling, which means removal of excess seedlings, affords better growth conditions and chances of success for future plants. It is done in areas regenerated either by pit or broadcast sowing. The best way to carry out singling in a cluster of seedlings, as in pit sowing, is to use a Y-shaped, short stick, winding and holding down unwanted plants in the fork and cutting them with a small axe, the obliteration being applied where stems rest against the stick (Bushara, 1974). Successful pit-sown areas should be thinned out by reducing the number of seedlings in
each pit to one, if vigorous, or two, if poor, the later being an insurance against loss through termites. In a very good crop this may be undertaken as early as December or January but normally should be done in April or May at the end of the dry season when the good survivors can be clearly seen. It must, however, be completed before the onset of the next rains after sowing to give the remaining plants full opportunity to develop during that rainy season (Foggie, 1968).

Singling a dense crop arising from broadcast sowing is a difficult operation. It can be combined with weeding where all plants, grass, weeds or trees being cut or hoed out between selected good seedlings at approximately 2 * 2m spacing. But this may be a fairly expensive and difficult operation … and it may be necessary to allow the crop to develop undisturbed until about 6 years old when it should be brashed and thinned and all wolf trees removed (Foggie, 1968).

If seeds are sown in July the plants will be about two feet high in December. The seedlings should then be singled out, to one per pit in the case of pit-sown seedlings or to a spacing of 2m by 2m for seedlings from broadcast seed or natural regeneration. If sowing is later the singling may be delayed, but it should always be done before the next rainy season after planting. At the same time as this singling out is done, odd trees of advance growth should be removed (Jackson, 1959).

Barlas (1949) outlined the following thinning treatment during first year of establishment:
(a) No thinning out of seedlings should be made, where the crop has resulted from broadcast sowing. The crop of seedlings may be left untouched. They will thin themselves naturally, as they grow older.
(b) Where the seed has been planted in "turia" pits resulting in several seedlings growing from the one hole, then all but one seedling must be cut out when 5-6 months old. In case where the ground is poor or the sowing has been made late in the year, then the seedlings if very weak can be left unthinned to grow on into their second year.

Increment, thinning, and rotation age: With respect to timing and intensity of thinning of sunt, Badi et al. (1989) report that on good sites the trees should have closed canopy and eliminated grass competition after four or five years. They will then be 25 to 30 ft. in height. Once the canopy is closed height growth becomes very rapid and there is intense competition within the stand. Some trees establish themselves as dominants and if the forest is left unthinned, rapidly suppress and kill out the remainder. During this period also wolf trees cause great damage by causing the other trees to bend away from their heavy crowns. Thus thinnings need to begin at about the sixth year, and because of the rapid rate of growth of the sunt, need to be repeated at frequent intervals, not exceeding three years. In good quality crops the period of most rapid height growth ends at about the twelfth years, when the tree will be about 60 feet (18 meters) high. After this height growth continues at a moderate rate until about the fifteenth year, after which it becomes slow. Thus heavier thinnings should be concentrated between the 6th and 12th years and then lighter thinnings made until the twentieth year when the crop should be at approximately the final spacing, about 50 trees per feddan (Jackson, 1959). It was a common practice in the past to select and mark the final felling crop early in the development stages of the A. nilotica plantations (Jackson, 1959). It was an approach for tree improvement since the best growing, large-stemmed trees with straight long boles were selected, usually after the third thinning at age 12 years. Successive thinnings are concentrated on removal of trees other than the marked 50 trees per feddan until age twenty (Elsiddig, 2002). The final rotation in the Fung is
fixed as 30 years. These remarks on thinning apply particularly to rapidly growing trees in the Fung, where they are grown to produce timber (Badi et al., 1989).

Jackson (1959) recommended heavy thinning for the first three thinnings during the period of rapid growth, and light thinnings for the rest of the time. He prescribed thinnings to be normally made in the 6th, 9th, 12th, 15th, and 20th years after sowing. By the 20th year the crop should be reduced to the final spacemen, being about 50 trees per feddan. Jackson further remarks `thinnings are required from about the sixth year onwards, and because of the rapid rate of growth of the Sunt need to be repeated at short intervals, not more than three years (De Veer, 1961).

A higher site quality requires earlier thinning for a given initial density because competition begins earlier (Danial et al., 1979). Optimum age for first thinning of stands on good soils should be 5 or 6 years (Booth, 1949) and the crop reduced to 500-600 stems per feddan (Foggie, 1969). Most fast growing plantations require thinning about every three years when young, five years in middle life, and less frequently when they are old. In early thinnings, one-third to one-fifth of the number of trees may be removed at each thinning. The thinning period, i.e. the interval between thinnings, depends on whether thinning is heavy or light (James, 1966). The practice of repeating thinning at equal intervals simplifies administration but has no other virtues. Actually stands should be thinned more frequently when young than when old because they close more rapidly. Total yield is augmented largely by harvesting trees that would ultimately die of suppression (Smith, 1986).

Khan (1964) produced provisional yield tables (appendix 1) for Acacia nilotica based on site quality classes. The tables indicate the number of trees, volume per unit area in a properly thinned crop. The first numerical guide to thinning practice in Sunt stands was made by Foggie

Eltayeb (1985) constructed a series of yield tables (appendix 2) of *Acacia nilotica* main crop and thinnings. The tables show the relationship between age as independent variable in one hand, and dominant and mid height; dbh, stem numbers/ha, basal area/ha, volume/ha, mean annual increment/ha and mean periodic increments/ha on the other hand. He has constructed site index curves and charts that relate the dominant height of the crop (16m, 19m, 22m, 25m, 28m) to its age in years (up to 36 years). The yield table is based on heavy thinning at the end and assumes the following thinning regime. Thinning starts at 6-9 years which is light thinning involves the removal of wolf, suppressed, dead and dying trees. Moderate thinning follows at age 12-15 years. Then heavy thinning is applied at the age of 18 years to leave the specified number of trees required per hectare. Rotation age for maximum volume production is 30 years.

Table 2. Foggie (1968) management strategy

<table>
<thead>
<tr>
<th>Year</th>
<th>Age years</th>
<th>Operation</th>
<th>DBH %</th>
<th>Stem removed</th>
<th>Remaining stems</th>
<th>Vol removed feddan</th>
<th>Stacked m³</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>pit sowing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1050</td>
<td></td>
</tr>
<tr>
<td>4-5'</td>
<td>5-6</td>
<td>1ˢᵗ thinning</td>
<td>3''</td>
<td>50</td>
<td>450-550</td>
<td>500-600</td>
<td>1.4m³</td>
</tr>
<tr>
<td>8</td>
<td>9</td>
<td>2ⁿᵈ thinning</td>
<td>5''-8.5''</td>
<td>45</td>
<td>250-300</td>
<td>250</td>
<td>2-4m³</td>
</tr>
<tr>
<td>11</td>
<td>12</td>
<td>3ʳᵈ thinning</td>
<td>7''-11''</td>
<td>30</td>
<td>75</td>
<td>175</td>
<td>3-6m³</td>
</tr>
<tr>
<td>14</td>
<td>15</td>
<td>4ᵗʰ thinning</td>
<td></td>
<td>20</td>
<td>35</td>
<td>140</td>
<td>6-15m³</td>
</tr>
<tr>
<td>17</td>
<td>18</td>
<td>5ᵗʰ thinning</td>
<td></td>
<td>20</td>
<td>30</td>
<td>110</td>
<td>6-15m³</td>
</tr>
<tr>
<td>20</td>
<td>21</td>
<td>6ᵗʰ thinning</td>
<td>12-16</td>
<td>(16)</td>
<td>(94)</td>
<td>11-14m³</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>24</td>
<td>7ᵗʰ thinning</td>
<td>12-16</td>
<td>(13)</td>
<td>(81)</td>
<td>11-14m³</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>27</td>
<td>8ᵗʰ thinning</td>
<td>12-16</td>
<td>(11)</td>
<td>(70)</td>
<td>11-14m³</td>
<td></td>
</tr>
</tbody>
</table>
Eltayeb (1985) management strategy involves 3 thinnings, 30-year rotation, and 5 site indices. The yield table is based on heavy thinning at the end and assumes the following thinning regime. Thinning starts at 6-9 years which is light thinning involves the removal of wolf, suppressed, dead and dying trees. Moderate thinning follows at age 12-15 years. Then heavy thinning is applied at the age of 18 years to leave the specified number of trees required per hectare. Rotation age for maximum volume production is 30 years.

Goda (1987) proposed a thinning regime for *A. nilotica* plantation based on site types on the basis of Khan (1964) yield tables. Table (3) displays stem numbers for the different thinning steps and total volume (m$^3$ ha$^{-1}$) for the different thinning steps according to Goda.

### Final felling and timber yield:
Badi *et al.* (1989) report that the average yield of the final cut is about 55 m$^3$ per ha of which about 4 m$^3$ are suitable for sawn-wood production. Foggie (1959) indicates that exploitable log volume is taken as 67% of gross stem volume for stands of QC I – II/III for a rotation of 35 years. The Inventory Directorate of the FNC reports current mean millable to non-millable wood ratio is in the range of 47% - 50% for a rotation of 25-27 years. In the Fung first quality sunt at the age of 24 years may produce up to about 2500 ft$^3$ (127 m$^3$) of saw logs, and 100 stacked m$^3$ of firewood per feddan, but average yields are of course much lower than this (Badi *et al.*, 1989).

CAB International (2000) reports that: "Estimates of productivity of plantations and natural stands vary considerably with site conditions .... Growth rate is relatively fast, with figures for
plantations on average sites of 3 to 5 cubic metres per hectare per year over a 15-20 year rotation, and maximum figures of from 3 to 9 cubic metres per hectare per year between ages 10 and 15 years in Rajasthan and Uttar Pradesh. In the Sind riverine forests a maximum mean annual increment of 13 cubic metres per hectare at age 20 years, and 10.5 cubic metres per hectare at age 30 years, on Quality 1 sites has been recorded. At 600 plants per hectare, 12 tonnes of bark was produced in a 15 year rotation. Pods are another useful product from the plantations, with yields of 8-10 tonnes of pods/ha/year. In India, stem circumference (girth) can develop to 2-3 m, with a clear bole height of 6 to 7.5 m (Troup and Joshi, 1983). Babool is a medium sized tree having height up to 10 meters, with a clear bole of 6-7 meters (Oudhia, 2001, 2002, 2003.)

Table 3. Stem numbers for the different thinning steps (after Goda, 1985).

<table>
<thead>
<tr>
<th>Site type Gerf slope - Karrab slope</th>
<th>Site type Maya</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td></td>
</tr>
<tr>
<td>Before thinning</td>
<td></td>
</tr>
<tr>
<td>After thinning</td>
<td></td>
</tr>
<tr>
<td>Stem no. ha⁻¹</td>
<td></td>
</tr>
<tr>
<td>Number removed</td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td></td>
</tr>
<tr>
<td>Before thinning</td>
<td></td>
</tr>
<tr>
<td>After thinning</td>
<td></td>
</tr>
<tr>
<td>Stem no. ha⁻¹</td>
<td></td>
</tr>
<tr>
<td>Number removed</td>
<td></td>
</tr>
</tbody>
</table>

Table 4. Total volume (m³ ha⁻¹) for the different thinning steps (after Goda, 1985).
Table: Economic evaluation of two management strategies of Acacia nilotica plantations grown for saw log production along the Blue Nile, south of Sennar Dam, Sudan.

<table>
<thead>
<tr>
<th>Year</th>
<th>Year</th>
<th>Coverage</th>
<th>Density</th>
<th>Yield</th>
<th>Sale Price</th>
<th>Revenue</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>70.7</td>
<td>30.5</td>
<td>40.2</td>
<td>8</td>
<td>79.7</td>
<td>720</td>
</tr>
<tr>
<td>10</td>
<td>109.7</td>
<td>42.2</td>
<td>67.5</td>
<td>13</td>
<td>193.1</td>
<td>450</td>
</tr>
<tr>
<td>14</td>
<td>207.4</td>
<td>74</td>
<td>133.4</td>
<td>22</td>
<td>284.4</td>
<td>250</td>
</tr>
<tr>
<td>20</td>
<td>292.6</td>
<td>113.8</td>
<td>178.8</td>
<td>34</td>
<td>298.8</td>
<td>250</td>
</tr>
<tr>
<td>28.5</td>
<td>336.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Final felling at 25 - 30 years:

Source: Goda (1985).

Opening of fire lines and inspection lines: The external fire lines form the boundary of the forest. They are to be cleaned to a minimum width of 6m... The operation is to be carried out after the rains, as soon as the ground has hardened and before the grass has dried. The internal fire lines are formed by the compartment boundaries and inspection paths. When they form compartment boundaries, internal fire lines are to be cleared to a width of 3m... Inspection paths are to be cleaned to a width of 2m. Cleaning of internal fire lines is to be taken up together with that of the external fire lines (Bushara, 1974). Because of some local conditions 10 meter fire lines are needed in some forests (Jackson, 1959) e.g. Lembwa and Hedaibat western boundary.

Control of flooding: The extent of flooding of individual forests by rain or river water is to a large extent outside the control of the Forests Department. Some control however can be affected by opening and closing of the canals in certain forests. In regulating these canals it should be borne in mind that heavy flooding is needed to regenerate the higher contours, while the lower contours need reduced flooding. Thus it may be possible first to flood the forest heavily for two or three years to regenerate the high land, and then to close the canal and reduce flooding so that the lower contours can be dealt with (Jackson, 1959).
Chapter three: Materials and methods

This study dealt with the even-aged forest stands of Sunt grown along the Blue Nile. The group of forests concerned are situated between the Sennar Dam (lat. 13° 43’ N, Long. 33° 37’ E) in the north and Roseries (Lat. 11° 50’ N, Long. 34° 32’ E) in the south. The study was targeting particularly establishment, tending and management operations, final felling operations, log sorting and transport and sawmilling operations at state mills of Es Suki and Wad En Nail. Appendix (3) shows summary of the organizational characteristics of forest reserves of *Acacia nilotica* along the Blue Nile south of Sennar dam.

3.1 Work and time studies for cost estimation:

3.1.1 Costing of forest operations:

In costing field operations a cost classification based on their physical location is followed. It distinguishes direct cost, oncost and overheads. Direct costs are identifiably incurred at the point of physical production. On costs, normally accounted at local level, are mostly associated with employing labour. It is normal to sum these costs, calculate them as a proportion of direct costs and to add this percentage to the direct labour cost of operations. Overheads are enterprise costs that cannot easily be assigned to any particular forest. Administrative and clerical services at every level from headquarters to local office are also included. Like oncost, overheads are normally added as a percentage on the direct costs and they may easily be of similar order of magnitude to direct costs (Price, 1989).

Work and time study techniques were used to generate data on labour productivity per unit time for the different silvicultural, harvesting and sawmilling operations. With the aid of stopwatch, cumulative method of timing was applied, i.e. the watch runs continuously throughout the study.
It was started at the beginning of the first element of the first cycle to be timed and was not stopped until the whole study was completed. At the end of each element the watch reading was recorded. The individual element times were obtained by successive subtractions after the study was completed. The purpose of this procedure was to ensure that all the time during which the job was observed was recorded in the study.

Equation (53) was used to determine the sample size or number of readings that must be made for each element, given a predetermined confidence limit and accuracy margin. Statistically this requires taking a number of preliminary readings (n'), first. Then apply the following equation for the 95.45% confidence level and a margin of error of ± 5 percent (ILO, 1981):

\[
    n = \left[ \frac{40 \times n' \times \sum X^2 - (\sum X)^2}{\sum X} \right]^2
\]

(53)

Where:

\[ n = \text{sample size}; \]
\[ n' = \text{number of readings taken in the preliminary study}; \]
\[ X = \text{values of the readings}. \]

This process resulted in sample size of 29 sample plots for seed sowing, 18 sample plots for singling, 32 sample plots for pre-commercial thinning, 79 trees for harvesting, 116 loads for skidding of logs and 36 loads for truck transport of logs.

**Seed sowing in pits:**

**Materials:** The operation was examined at compartment 13 (area is 63.35 feddan) of Gazair Forest Reserve, El Gezair Division, Es Suki Forest Circle. The compartment was selected as it
was due replanting in 2002 and shows a typical representation of the topography of the Blue Nile basin, i.e. gerf, maya, and karab.

Methods: In total 15 sample plots were made and the times used to seed-sow them were recorded. Being on-farm research, sample size was influenced directly by the conditions of flood water recession. The work cycle consisted of the following elements: digging of planting holes at spacing of approximately 2m * 2m, placing of 5-10 seeds into the planting hole and covering them with earth. The crew consisted of two youthful workers with experience in agricultural production. The first worker digs the planting hole while the second places the seeds into the pit and lightly covers them with soil. These two roles were played alternatively. The sample plots were sown in different days, but it was deemed critical to have approximately the same level of wetness across them. The holes were prepared to a depth of 15-20 cm with a locally produced hoe (turia). Seeds were placed with hand and earth-covered with foot, as is the common planting method in the locality.

Singling of newly established A. nilotica seedlings:

Materials: The operation was investigated at compartment 13, El Gazair Forest Reserve, El Gezair division, Es Suki Forest Circle. The operation was carried out during January 2002 on a crop established in November 2000 by pit sowing utilizing a taungya system that involved water melon (Citrullus lanatus) as a companion crop.

Methods: In total 18 sample plots were made and the time used to single them was recorded. The work cycle consisted of careful selection of trees to be removed on the basis of removing the dead, dying, diseased, etc., leaving trees with a maximum interspacement of approximately 2m * 2m. A number of causal youthful workers with experience in agricultural production were
employed. The operation involved the use of Y-shape stick to separate the tree to be cut using the ordinary locally made axe.

*Pre-commercial thinning operations:*

*Materials:* First pre-commercial thinning was assessed at two forest reserves, i.e. compartment 15 in El Gezair forest reserves and compartment 10 in Zumurka forest reserve.

Methods: 32 and 45 sample plots were made at El Gezair and Zumurka forest reserves, respectively. Rectangular sample plots 35m*15m (1/8th feddan) were used to assess time requirement. In each sample plot a sub-plot 4m*4m was randomly delineated and the number of stems removed and those remaining were counted to assess stocking. Two trained forest workers used pruning power saws were involved in the operation.

### 3.1.2 Costing of sawmilling and sawmilling-related operations:

*Felling and crosscutting of final-crop trees of Acacia nilotica*

*Materials:* The operation was observed at four locations. (a) Es Suki Forest Circle, Abu Tiga division, Zumurka Forest Reserve, Compartments 1; (b) Es Suki Forest Circle, El Gezair division, El Gezair Forest Reserve, Compartments 10; (c) Es Suki Forest Circle, El Gezair division, Wadelais Forest Reserve, Compartments 2, 4, 7; and (d) Singa Forest Circle, Wad En Nail division, Hedaibat Forest Reserve, Compartments 5&6.

Methods: A total of 100 trees were felled and the combined time of felling and bucking was recorded. The operation included 32 trees, 31 trees, 26 trees and 5 trees at Zumurka, Hedaibat, El Gezair, and Wadel Ais forest reserves, respectively (the records of 6 trees were missed while in
Tree diameters ranged between 25 and 74 cm. The trees were later put into diameter classes of 10 cm intervals.

The work cycle consisted of the following elements: cutting of felling notch, felling of the tree, and deliming, crosscutting -de-branching- crosscutting. The operators were primarily saw doctors who have undertaken high level training and have acquired experience in felling of trees for more than 20 years. A felling team consisted of a machine operator and an assistant. The sawing machine used was of the type Makita DCS 9010, (22045 Hamburg, Germany) with a guiding bar of 76.2 cm (30 inch) length. The machine originally operates with normal benzene as fuel and engine oil 30. The chain is liable to be sharpened and replaced. The main stem and large branches were divided into saw logs of varying lengths according to utilization standards that are based on the stem form and length and mid girth over bark (GOB). The current utilization standards classify logs into logs for state sawmills and logs for private sawmills. Logs for state sawmills have mid GOB of ≥32 inch. Logs for private sawmills have mid GOB of 28-32 inch. Wood with a mid GOB <28 inch is classified as firewood. Only during the felling period of 2002, mid GOB of logs for private sawmills were raised up to 35 inch.

For each tree felled the readings made were DBH in cm, height in meters and pole height (height of clear stem to the first major branching). The basic times for the following elements were recorded: Cutting of felling notch, felling of the tree, de-branching, deliming and cross cutting. Stump height and Stump diameter were read for each tree felled.

The major variables in felling and bucking are the tree diameter and the number of bucking cuts after felling (FAO, 1992). The production rate, P, in m$^3$ per hour is
\[
P = \frac{V}{T} \quad (54)
\]

Where \(V\) = volume per tree (m\(^3\)); and \(T\) = time per tree (hour)

The unit cost (UC) of felling is

\[
UC = \frac{C}{P} \quad (55)
\]

Where \(C\) = the machine rate for felling and bucking; and \(P\) = production rate.

To estimate the number of logs produced from final-crop trees of *Acacia nilotica* under the current management strategy, and the number of bucking cuts, a total of 37 trees were cross cut. Logs produced were counted and sorted out into state and commercial logs. 17 trees comes from Hedaibat forest reserve (Site index 25) while 20 trees were cut at Gezair forest reserve (Site index 16).

**Skidding of logs:**

*Materials:* This operation was studied at Compartments 5&6, Hedaibat Forest Reserve, Wad En Nail division, Singa Forest Circle. The study aimed to estimate the time and cost of skidding logs of *Acacia nilotica* final-crop trees.

*Methods:* Sixty-one loads carrying 117 logs were examined and the times of the different elements were recorded. Logs were transported by skidding them resting on the ground. The work cycle consisted of the following elements: Unloaded trip from the landings to stump site; Hooking of logs; Loaded trip from stump site to landings; Unhooking of logs at the log depot. Cumulative method of timing was applied. The basic times for the following elements were observed for each work cycle: travel time of unloaded trip; time of hooking of logs; travel time of loaded trip; and time of unhooking of logs at the log depot. The skidding operation at Hedaibat forest was performed with the aid of an ordinary private farm tractor equipped with
hooked chain. The practice involved a total of three labours, two for hooking and one for unhooking of logs.

Skidding production is estimated by dividing the volume per load by the time per round trip. The round trip time, $T$, is the sum of the times for travel unloaded, hooking, travel loaded, and unhooking (FAO, 1992).

$$T = aN + b_1 x_1 + b_2 x_2. \quad (56)$$

Where:

- $a$ is the combined time for hooking and unhooking per log;
- $N$ is the number of logs per trip;
- $b_1$ is the minutes per meter for loaded travel;
- $x_1$ is the distance from the landing to load pickup point; and
- $x_2$ is the distance from the load pickup point to the landing;
- $N$ is the number of logs per trip.

If the outhaul distance and inhaul distance are the same, the roundtrip time can be expressed as

$$T = aN + b x \quad (57)$$

Where $b$ is the minutes per roundtrip distance and $x$ is the one-way distance; $N$ is the number of logs per load. The coefficient $b$ is calculated as

$$b = \frac{(v_1 + v_2)}{v_1 v_2} \quad (58)$$

Where $v_1$ is the travel speed unloaded and $v_2$ is the travel speed loaded.
Truck transport of logs:

Materials: This operation was examined at 3 locations: (a) compartment 10, El Gezair Forest Reserve, El Gezair division, Es Suki Forest Circle (b) compartments 2, 4, & 7, Wadelais Forest Reserve, El Gezair division, Es Suki Forest Circle (c) compartments 5 & 6, Hedaibat Forest Reserve, Wad En Nail division, Singa Forest Circle.

Methods: A total of 62 loads were examined. 41 loads, carrying 1050 logs, were made at Hedaibat stump area, while 21 loads, carrying 495 logs, were made at El Gezair-Wadelais forests group. In Hedaibat stump area the logs were skidded to a number of load picking points. The trucks, therefore, collected the whole load from a single point unless extra logs were needed from another point. In El Gezair-Wadelais group no prior skidding was done. The truck, therefore, moved continuously to collect logs one by one.

The work cycle consisted of the following elements: the unloaded trip from the sawmill to the stump area, loading of logs, loaded trip from the stump area to the sawmill, and unloading of logs at the sawmill yard. The activity was done on the basis of a per-log contract. The operators were primarily casual labours from the vicinity of the sawmill. The loading and unloading operations were made manually. In Hedaibat stump area the working team in average consists of 8-12 members who change their roles regularly. In average 7-9 workers performed the loading part of the operation, while 1-3 workers worked on the truck deck to place, to arrange and rearrange logs. In El Gezair-Wadelais stump area the team consisted of 5-10 workers who worked together in loading and unloading operations. The loading is anti-gravity and was made easy by the use of two wooden posts supported to the truck deck to ease rolling of logs upwards. 4-5 workers drag the logs by rolling them from the log pile to the truck and raise them by rolling
them up the wooden posts, 1-3 workers on the truck deck to place, arrange and rearrange logs. Cumulative method of timing was applied here, too.

For each load transported, readings were made for number of logs loaded; volume of logs loaded; number of workers involved; travel distance to and from the stump area. The basic times for the following elements were recorded: unloaded travel trip time; loading time; loaded travel trip time and unloading time.

The method of estimating truck production depends upon the purpose of the analysis. If truck production is being calculated for the purpose of determining the number of trucks needed for truck haul, then the average truck load is divided by the total roundtrip time including unloaded travel time, loading time, loaded travel time, and unloading time. The calculation is similar to that for skidding with the roundtrip travel time, $T$, expressed as

$$
T = a + b_1x_1 + b_2x_2 \quad (59)
$$

Where: $a$ is the combined time for loading and unloading; $b_1$ is the hours per Km for unloaded travel, $b_2$ is the hours per Km for loaded travel; $x_1$ is the distance from the landing to load pickup point; and $x_2$ is the distance from the load pickup point to the landing. If the outhaul distance and inhaul distance are the same, the round trip time can be expressed as

$$
T = a + bx \quad (60)
$$

Where $b$ is the hours per round trip Km and $x$ is the one-way distance. The coefficient $b$ is calculated as in equation (58).
**Sawing of state logs into railway sleepers and other sawn wood products**

**Materials:** This study was carried out at Es Suki state mill to estimate the conversion factor of logs produced from final-crop trees of *Acacia nilotica* and to estimate production cost per unit of sawn wood, particularly SRS.

**Methods:** 30 logs with a length of 7 feet each and amid girth over bark ranging between 38 inch and 64 inch were sawn. The saw logs were processed and the products of each log were sorted and recorded separately. The conversion factor was calculated for each individual log separately and for all logs together. Productivity records of Es Suki mill for the period February 1999 to April 02 were examined to reach to mean productivity per unit time.

**Office, forest, farm and market surveys**

Combined methods of participant observation during seed collection campaigns, interviews of National Seed Center (NSC) team leader in charge of seed collection and the annual seed collection reports of the NSC were used to collect data on quantities of seed collected annually and quantities used in seed sowing as well as the cost of their treatment. A market survey was made to collect data on Sennar market price of Sulphuric acid, as well as the cost of treatment labour and electricity for driving the treatment machine.

Some other tending or support operations were not examined in the field. Some are not currently part of the annually performed operations (e.g. opening of channels (Sagai), or very variable (e.g. weeding, protection), or dependant on rainfall (e.g., singling out seedlings at one year age or less, opening of fire lines, climber cutting). Data related to these operations were obtained through office surveys on secondary sources of information and direct interviews of key informants.
3.2 Estimation of the technical rotation for sawlog production:

*Materials*: Yield tables of Sunt stands of site indexes 16, 19, 22, 25, and 28 (based on yield tables produced by Eltayeb (1985) for ages 6 to 35 years. Es Suki sawmill production records concerned with minimum log dimensions required to produce SRS. Results of previous similar studies of Jackson (1959) and Nile (1996) who investigated 100 and more than 300 logs, respectively, were utilized. The selection of Eltayeb (1985) yield tables as a reference to the biological productivity was made because of a number of reasons. First, they are based on site productivity potential. Second, they were prepared on the bases on permanent sample plots. Third, they extend to 36 years thereby allowing the testing of the two management strategies under examination. Fourth, they were the last to be produced for Sunt stands, and finally they treat age as independent variable a fact that is particularly needed in the financial and economical cost benefit analyses.

*Methods*: The minimum log dimensions required to produce SRS at public sawmills were investigated and the least crop ages of stands of site index 22, 25 and 28 that produce logs with diameters large enough to produce single, double or triple SRS were examined.

3.3 Determination of financial rotation

3.3.1 Estimation of millable wood percent during the rotation:

*Materials*: Eltayeb (1985) yield tables of even aged Sunt stands were the source that provide the dbh and mid height data for crops grown on site index 22, 25, and 28 which are specifically addressed in this proposal as potentials for the production of saw logs.

*Methods*: The proposed percentages are made for a crop that would be managed according to the management strategy prescribed by Eltayeb (1985) and the associated yield tables. An
observational study (2002) at, Hedaibat, Zumurka, Gezair stump sites (N = 37) revealed that mean stump height (felling is made with the aid of power saws) was 25.3 cm above ground level. Therefore, the dbh of a tree falls closely to the middle of first log. It was assumed to be equal to its mid-log diameter. Mid diameters of subsequent logs lie at multiples of log length (2.1 m).

A study of the relationship of diameter at small-end and mids of logs produced from final felling compartments (N = 111); age = 25; SI 25, 2002) at Hedaibat stump site is described by equation (61) and is shown graphically in appendix (4).

\[ Y = -1.18 + 0.987 \times X \quad (61) \]

\[(r^2 = 0.94)\]

where

\[ Y = \text{small-end (OB) diameter (cm)}; \]

\[ X = \text{mid-log (OB) diameter (cm)} \]

Use was made of the result obtained above to estimate the mid diameter of subsequent logs. Each tree was assumed as consisting of a series of successive log-long (2.1 m) sections. It was assumed that saw logs are produced only from the main stem and none from the branches. Numbers of logs to be produced from single trees at various ages and for the five site indexes were estimated up to a minimum of 25 cm mid diameter (when commercial logs are included) and up to a minimum of 35 cm mid diameter (when only state logs are included). Log-long sections were grouped in diameter classes commencing at 25 cm with a range of 5 cm, their respective volumes were calculated applying Huber's formula (eq. 62) which involves the use of sectional area of mid log and log length. Volumes of logs were added to give the millable volume of a single tree.
\[ V = \frac{d^2}{4 \cdot 10^4} \cdot \Pi \cdot L \]  

(62)

Where:

\[ V = \text{log volume in m}^3; \ d = \text{mid log diameter in cm}; \ L = \text{log length in meters} \]

Bole height: total height ratio is used as an indicator of management intensity where 0.3, 0.5 and 0.75 bole height: total height ratios are treated as low, medium and high level management, respectively. Seven ratios of bole height to total tree height were tested (0.3, 0.4, 0.5, 0.6, 0.7, 0.75 and 0.8). Counting of logs started from the stump of the tree upwards. Logs that could potentially be produced at heights beyond the bole height in each alternative ratio were ignored.

Volume of single trees was calculated using the basal area, total height and a form factor (eq. 63).

\[ V = \frac{D^2}{4 \cdot 10^4} \cdot \Pi \cdot t \cdot f \]  

(63)

where :

\[ t = \text{total height in meters}; \ f = \text{form factor}; \ D = \text{dbh in cm} \]

The bole form factor (f) used is that estimated by Elsiddig and Hetherington (1985) as presented in equation (64) for sites of quality class I.

\[ f = 0.931 + 0.0022D - 0.0232hb \]  

(64)

where:

\[ f = \text{form factor} \]

\[ D = \text{diameter at breast height} \]

\[ hb = \text{bole height in metres} \]
Relating the millable volume to total volume of single trees and multiplying the result by 100, provided the percentage of millable wood volume to total wood volume for various ages and site indices, based on single tree statistics. Similar percentages were made for sawlogs that are capable of producing railway sleepers, only.

3.3.2 The financial rotation age of Sunt stands under FMS and JMS:

Materials: Yield tables of even aged Sunt stands of site indexes 22, 25, and 28 produced by Eltayeb (1985) for ages 6 to 35 years.

Methods: The “total” approach that aggregates predicted costs and revenues of various rotations and select the rotation of highest NPV, was used for the analysis. Net present value of bare land at 12% before tax rate of return was investigated. For estimation of financial rotation, Net present values were calculated for 2 management strategies and 3 site indexes. Assuming a minimum of 5 years interval between last thinning and final felling in each case, applying the BLV equation, NPV for rotation ages 26 to 30 in the Jackson Management Strategy (JMS), and 33 to 35 in the Foggie Management Strategy (FMS) were calculated to trace the financial rotation for sawlog production.

The analysis was extended to include production of railway sleeper. The present value of a perpetual periodic income was estimated using the per feddan net income from sleeper production for each of JMS and FMS and added to the net present value per feddan of sawlog production to give the net present value per feddan with sleeper production inclusive.
Bole to total height ratio of 0.3 and the associated percentages of millable and non-millable wood is used for the financial analysis as it closely represents the current productivity status. A bole to total height ratio of 0.75 and the associated percentages of millable and non-millable wood is used for the sensitivity analysis. The choice of this ratio is made on the fact that the mean millable wood percent for the three site indexes is 66.8% at rotation age of 35 years, which is similar to the 67% exploitable volume reported by Foggie (1968).

Equation (23) of the bare land value was used for the determination of rotation length of an indefinite horizon. The analysis is carried from the FNC perspective. The growth function and thinning yields are based on Eltayeb (1985). Cost of first thinning is estimated on per feddan; while that of other thinnings are made on per m³ of standing firewood. Constant (2002) market prices are used for both inputs and outputs, with land value equal to zero in the financial analysis. Wood output from thinning and final cutting consists of varying proportions of millable and non-millable wood.

Final felling cost is S.D. 27.4 and S.D. 959.6 per ft³ and m³, respectively. Constant, rather than increasing, prices were used for inputs as well as outputs. Profit margin used was 12% per annum. 2002 constant price, support and forest camp fees per unit of output are shown in table (5).

Net income per feddan from sawmilling operations for sleeper production, which is received at regular rotation-length periods and continues for infinity is capitalized using the formula (equation
of present value of a perpetual periodic series. Appendix 28 displays the methodology for of
NPV per feddan with sleeper production inclusive.

\[ V_0 = \frac{P}{(1 + r)^t - 1} \]  

(65)

where:

- \( r \) = annual interest rate/100
- \( P \) = amount of fixed payment each time in a series,
- \( t \) = number of years between periodic occurrences of \( P \).

Table 5. Prices (SD) of wood outputs of final felling (2002)

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Price/unit</th>
<th>Support fees</th>
<th>Forest camp fees</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Millable round wood (Solid)</td>
<td>ft³</td>
<td>190</td>
<td>23</td>
<td>0</td>
<td>213</td>
</tr>
<tr>
<td>2. Millable round wood (Solid)</td>
<td>m³</td>
<td>6710</td>
<td>812</td>
<td>0</td>
<td>7522</td>
</tr>
<tr>
<td>3. Firewood (Standing)</td>
<td>m³</td>
<td>2655</td>
<td>390</td>
<td>150</td>
<td>3195</td>
</tr>
<tr>
<td>4. Firewood (Solid)*</td>
<td>m³</td>
<td>3739</td>
<td>549</td>
<td>211</td>
<td>4500</td>
</tr>
</tbody>
</table>

SD. = Sudanese Dinars; * Stacked to solid volume ratio = 0.71

3.4 Productivity status of existing Sunt stands:

*Materials:* Eight compartments in four forest reserves were used for estimation of productivity
per unit area of existing final felling compartments. Sampling covered the compartments due
felling in 2002, the characteristics of which are shown in table 6.
Table 6. Characteristics of final felling compartments due felling 2002

<table>
<thead>
<tr>
<th>Year</th>
<th>State</th>
<th>Forest reserve</th>
<th>Cmpt</th>
<th>Area (feddan)</th>
<th>Stocked area (feddan)</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>Blue Nile</td>
<td>Saolil</td>
<td>1</td>
<td>58.8</td>
<td>56</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Sennar</td>
<td>Wadel Ais</td>
<td>2</td>
<td>13.58</td>
<td>5.82</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wadel Ais</td>
<td>4</td>
<td>36.65</td>
<td>23.13</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wadel Ais</td>
<td>7</td>
<td>84.19</td>
<td>65.11</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>Zumurka</td>
<td></td>
<td>6</td>
<td>53</td>
<td>22.14</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>Gazair</td>
<td></td>
<td>10</td>
<td>47.38</td>
<td>18.61</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Hedaibat</td>
<td></td>
<td>5</td>
<td>60</td>
<td>43.1</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>6</td>
<td>88</td>
<td>73.52</td>
<td>25</td>
</tr>
</tbody>
</table>


**Methods:** Random circular samples were drawn to estimate the number of trees per unit area. Samples drawn had a radius of 17.84m resulting, therefore, in a sample area of 0.10 ha. Sampling was made for final crop trees only. Sampling intensity of 5% of the stocked area of each compartment was targeted. Trees in each sample plot were tallied and numbered in sequence, their dbh were measured using caliper, and recorded. The heights of the largest 10% of the trees in each sample plot were measured using Suntto clinometers. The mean height of the top trees was used against the age of the crop to determine the site index of the compartment, using yield tables produced by Eltayeb (1985) as a reference.

The solid volume (m$^3$ ha$^{-1}$) was estimated using equation (66):

$$V / \text{ha} = \frac{D^2}{4 \pi f} h \cdot n$$  \(66\)

Where:

- \(V\) = volume in m$^3$ per ha;
- \(D\) = diameter at breast height (in decimals);
- \(h\) = tree height in meters;
The actual yield of the final felling compartments was also obtained from the final reports made by the Inventory Directorate of the FNC. These reports classify yield of final cut into millable solid volume delivered to state and private mills and firewood stacked volume sold for firewood traders.

3.5 Financial cost benefit analyses of alternative management strategies:

*Materials*: The income stream was composed of the wood yield per unit area along the rotation as depicted in the yield tables of stands of site indexes 22, 25 and 28, and the associated prices. The cost stream was made up of unit cost of various silvicultural and management operations as prescribed in each of the candidate management strategies. Both prescribed FMS and JMS were studied.

*Methods*: Direct interviews with FNC officials as well as secondary sources of information and archives were used to elicit information on prices of wood products e.g. state and commercial logs, the process of bidding for firewood produced from final felling operations, the process of determining unit price from thinnings at various stages, and taxes and subsidies levied on wood products.

The management strategies analyzed in this study involve a 3-year thinning intervals. 5-year interval between last thinning and final cut is assumed for the financial analysis of a series of potential rotation age. Land is considered the fixed input in the production process for which a
residual value was calculated. The WPL is a net present value designed for bare forestland – the present value of future revenues minus the present value of future costs, calculating just before reforestation or the net present value of the forest at rotation-start (Klemperer, 1996). The infinite time horizon ($WPL_{\infty}$) is relevant for cases where land sale is absolutely impossible or highly improbable, for example, on certain public lands. However, many forest owners change land use or sell land before or after harvest, or at least consider the option. A willingness to pay for bare land, assuming land sale after one rotation $WPL_1$ is applied as the two approaches can yield different optimal rotations (Klemperer, 1996). The $WPL_{\infty}$ was applied for the $A. \text{nilotica}$ plantations as publicly owned forest reserves. However, for comparative purposes $WPL_1$ was highlighted. Sensitivity analyses made include reduction of establishment cost through the application of taungya system, advancement of thinning by one year for site index 28, a combination of taungya practice and advancement of thinning, improvement of millable volume per unit area, delay of regeneration, and change in yield per unit area. Accordingly, Net present values per feddan of alternative management strategies of $A. \text{nilotica}$ grown for saw log production for both perpetual series of like rotations and for a single rotation were calculated for five management scenarios in each of the JMS and FMS for two bole height: total height ratios of 0.3 and 0.75. For a single as well as perpetual series of like rotations the base and alternative models were denoted as follows:

**Base models:**

FMS$_0$, JMS$_0$ Bole: total height ratio of 0.3; the prescribed management strategy; all 3 site indexes (Base model)

FMS$_1$, JMS$_1$ Bole: total height ratio of 0.75; the prescribed management strategy; all 3 site indexes (Alternative model 1)
Establishment of *A. nilotica* stands through taungya:

FMS\textsubscript{2}, JMS\textsubscript{2} Bole: total height ratio of 0.3; the prescribed management strategy; crop establishment through taungya system; all 3 site indexes (Alternative model 2)

FMS\textsubscript{3}, JMS\textsubscript{3} Bole: total height ratio of 0.75; the prescribed management strategy; crop establishment through taungya system; all 3 site indexes (Alternative model 3)

Advancement the timing of thinning in stands of site index 28:

FMS\textsubscript{4}, JMS\textsubscript{4} Bole: total height ratio of 0.3; thinning made 1 year in advance; site index 28 only (Alternative model 4)

FMS\textsubscript{5}, JMS\textsubscript{5} Bole: total height ratio of 0.75; thinning made 1 year in advance; site index 28 only (Alternative model 5).

Advancement of the timing of thinning in stands of site index 28 established through taungya:

FMS\textsubscript{6}, JMS\textsubscript{6} Bole: total height ratio of 0.3; crop establishment through taungya system; Thinning made 1 year in advance; site index 28 only (Alternative model 6).

FMS\textsubscript{7}, JMS\textsubscript{7} Bole: total height ratio of 0.75; crop establishment through taungya system; Thinning made 1 year in advance; site index 28 only (Alternative model 7).

Delay of regeneration:

FMS\textsubscript{8}, JMS\textsubscript{8} Bole: total height ratio of 0.3; the prescribed management strategy; all 3 site indexes (Base model), regeneration delayed one Season.
Change in yield per unit area:

FMS\textsubscript{10}, JMS\textsubscript{10} Bole: total height ratio of 0.3; the prescribed management strategy; all 3 site indexes (Base model), replacing yield per feddan of final cut (2002) for prescribed one.

3.6 Limitations and constraints:

The fieldwork of this research has encountered a number of important constraints that have direct bearing on the quantity, quality of data and time used.

The on-farm nature of field research: conditions on farm are far from being identical e.g. soil moisture contents for seed sowing in pits. The sample size is frequently determined by personal judgment of the researcher. Sample plot area, therefore, may not necessary is equal. Uniformity of sample plot area is sacrificed for uniformity of soil moisture.

Absence of permanent sample plots: Forest management for timber production is a long-term business that requires a continuous observation of growth function over time. The simplest way to guarantee that is through the establishment of permanent sample plots extending through the rotation limit. The permanent sample plots established earlier within the Sunt forests of the Blue Nile do no longer exist, unfortunately. This leads to research directly on existing plantations. Currently, the *Acacia nilotica* plantations along the Blue Nile don't exhibit the characteristic of age gradation of the normal forest. Further, the forests haven't being subjected to a precise and unified management strategy

Non-representative and incomplete coverage of sampling: Because of the absence of permanent sample plots, the research was carried out in place and time as dictated by the on-going programs
of the FNC. Sampling was not completely random and this will affect the generalization of the results.

*Past management credentials:* Stumpage valuation requires the use of past management details in both cost and benefit streams. Past information on various forestry operations are incomplete, if not completely lacking. A notable example is the timing of thinnings, their wood yields, costs and generated incomes. This leads to resort to the use of published or unpublished results of earlier research work e.g. yield tables. Such details are very vital for the determination of the economic feasibility of timber producing projects.
Chapter four: Results

4.1 Work and time studies for cost estimation:

4.1.1 Costing of forest operations:

Table (7) displays a summary of the cost of forest operations. Appendices 5, 6 and 7 illustrate the detailed calculations for seed sowing, singling and pre-commercial thinning, respectively.

Table 7. Summary of operational costs (SD) of some forest operations:

<table>
<thead>
<tr>
<th>Operation</th>
<th>Cost per</th>
<th>Days/feddan</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ft³</td>
<td>m³</td>
</tr>
<tr>
<td>1. Costing field operations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seed sowing</td>
<td>5953.3</td>
<td></td>
</tr>
<tr>
<td>Singling (El-Gezair)</td>
<td>5121.3</td>
<td></td>
</tr>
<tr>
<td>First thinning (El Gezair)</td>
<td>1784.4</td>
<td>1.0</td>
</tr>
<tr>
<td>CFCC¹ (El Gezair)</td>
<td>748.0</td>
<td>11340.0</td>
</tr>
<tr>
<td>CFCC (Hedaibat)</td>
<td>1357.7</td>
<td>44830.7</td>
</tr>
<tr>
<td>AGP² (El Gezair)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>AGP³ (Hedaibat)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Office and forest surveys</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Opening of fire lines</td>
<td></td>
<td>100.0</td>
</tr>
<tr>
<td>Opening of inspection lines</td>
<td></td>
<td>85.0</td>
</tr>
<tr>
<td>Establishment of Zariba</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Opening of Sagaya</td>
<td></td>
<td>210.0</td>
</tr>
<tr>
<td>General administration</td>
<td></td>
<td>2500.0</td>
</tr>
<tr>
<td>Removal of weeds e.g. tarfa</td>
<td></td>
<td>2000.0</td>
</tr>
<tr>
<td>Climber cutting</td>
<td></td>
<td>2333.3</td>
</tr>
<tr>
<td>First weeding</td>
<td></td>
<td>6500.0</td>
</tr>
<tr>
<td>Second weeding</td>
<td></td>
<td>4000.0</td>
</tr>
<tr>
<td>land clearance</td>
<td></td>
<td>2000.0</td>
</tr>
<tr>
<td>3rd weeding</td>
<td></td>
<td>2000.0</td>
</tr>
</tbody>
</table>

Source: This survey
1. One $US = SD. 260 at time of study, approximately. 2. CFCC = Combined felling and crosscutting 3. AGP = Annual general protection 4. Manday and machine day = 6-working hours. 5. SD= Sudanese Dinar.
4.1.2 Costing of sawmilling and sawmilling-related operations:

Table (8) displays a summary of the cost of sawmilling operations. Appendices 8, 9 and 11 illustrate the detailed calculations of costing combined felling and cross cutting, skidding and log transport per cubic unit and per feddan at Hedaibat stump site, respectively. Appendix 10 shows number of logs and millable volume percentages of final-crop trees.

<table>
<thead>
<tr>
<th>Operation</th>
<th>Cost per</th>
<th>Days/feddan</th>
<th>Mandays per</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ft³</td>
<td>m³</td>
<td>feddan</td>
</tr>
<tr>
<td>Felling (El Gezair)</td>
<td>28.4</td>
<td>992.8</td>
<td>23331.4</td>
</tr>
<tr>
<td>Felling (Hedaibat)</td>
<td>27.4</td>
<td>959.1</td>
<td>57433.5</td>
</tr>
<tr>
<td>Skidding (Hedaibat)</td>
<td>7.2</td>
<td>253.3</td>
<td>6235.1</td>
</tr>
<tr>
<td>Log transport (El Gezair)</td>
<td>51.7</td>
<td>1809.0</td>
<td>21814.6</td>
</tr>
<tr>
<td>Log transport (Hedaibat)</td>
<td>44.9</td>
<td>1601.1</td>
<td>40170.0</td>
</tr>
<tr>
<td>Sawmilling (Es Suki @40%)</td>
<td>235.8</td>
<td>8252.3</td>
<td></td>
</tr>
<tr>
<td>Sawmilling (Es Suki @46%)</td>
<td>205.4</td>
<td>7189.0</td>
<td></td>
</tr>
<tr>
<td>Sawmilling (Es Suki @54%)</td>
<td>174.7</td>
<td>6114.5</td>
<td></td>
</tr>
<tr>
<td>Sawmilling (Es Suki @60%)</td>
<td>157.5</td>
<td>5512.5</td>
<td></td>
</tr>
<tr>
<td>SRS sleeper (Es Suki @40%)</td>
<td>2266.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SRS sleeper (Es Suki @60%)</td>
<td>1514.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: This survey.

1. CFCC = combined felling and cross-cutting; 2. AGP = Annual general protection. SD = Sudanese Dinar.

The conversion factor at Es Suki sawmill is estimated as equal to 60% when all sawn wood products were taken into account, and is equal to 54% when considering only SRS. Appendix (12) displays the details. The conversion factor of Es Suki sawmill during the period February 2000 to April 2002 was 45.8%. The mean daily round wood intake was 10 m³ (350.2 ft³) and 160.2 ft³ for daily output of sawn wood. Appendix (13) displays sawmilling cost per cubic foot.
of sawn wood at Es Suki sawmill. Appendix (14) displays the costs of production of SRS at Es Suki sawmill. Appendix 15 displays the cost per feddan of general protection.

4.2 The technical rotation for sawlog production:

Table (9) displays the minimum mid log diameters required to produce the indicated product categories at sawmill conversion factor of 40%, and the ages that correspond to technical rotation limits for Sunt stands of site indexes 16, 19, 22, 25 and 28 for respective product categories.

<table>
<thead>
<tr>
<th>Product category</th>
<th>Mid log diameter (cm)</th>
<th>Stands of site index</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>28 25 22 19 16</td>
</tr>
<tr>
<td>Single sleeper</td>
<td>36-47</td>
<td>14-20 18-28 25-36</td>
</tr>
<tr>
<td>Double sleepers</td>
<td>48-55</td>
<td>21-28 29-36</td>
</tr>
<tr>
<td>Triple sleepers</td>
<td>56-64</td>
<td>29-36</td>
</tr>
<tr>
<td>Tetra sleepers</td>
<td>65-68</td>
<td>&gt;36</td>
</tr>
</tbody>
</table>

Source: This survey; Nile (1997, adapted); Jackson (1959).

Results show that Sunt stands of site index 16 and 19 are potentially not capable of producing logs large enough to yield railway sleepers. Stands of site index 22 are marginal as far as production of sawlog large enough to yield railway sleepers is concerned. The site produces logs that yield a single railway sleeper at age commencing at 25 years. Stands of site index 25 produces logs that yield one and two sleepers at 18 and 29 years of age, respectively. Stands of site index 28 starts producing logs that yield single, double, and triple sleepers at age 14, 21, 29 years, respectively.
4.3 Determination of optimal rotation

4.3.1 Estimation of millable wood percent during the rotation:

Figures (1a, 1b & 1c) display the estimated millable percentages of total wood volume for 0.3, 0.5 and 0.75 bole: total height ratios, respectively, for the 3 site indexes. These percentages include commercial as well as state logs. Figures (1d, 1e & 1f) display the estimated millable percentages of sleeper-logs only for 0.3, 0.5 and 0.75 bole: total height ratios, respectively, for the 3 site indexes. These percentages relate only to saw logs that are capable of producing railway sleepers. Appendix (16) displays proposed percentages of total and sleeper-log millable wood for bole: height ratios of 0.3 through 0.8 for the 3 site indexes during the rotation.

4.3.2 The financial rotation age of Sunt stands under FMS and JMS (base model):

Appendixes 17a and 17b display costs and benefits streams of alternative management strategies prepared with the aid of data generated in this study.

Strict application of JMS with 5th last thinning at age 20, a rotation of 30 years and a minimum of five years between last thinning and final cut and low level of management (0.3) lead to the following results. The highest NPV per feddan is achieved at rotation age 26. The higher NPVs are 59.8, 36.4, 11.8 thousand Dinars for stands of site index 28, 25, and 22, respectively. The financial rotation age under JMS is, therefore, 26 years. Figure (2a) displays the Net present value per feddan for a perpetual series of rotation length of 26 through 30 years for Jackson prescribed management strategies (base model). At high management level (0.75) the higher NPVs are 74.3, 48.7, and 22.5, respectively (figure 2c). End of rotation net income per feddan at low level of management amounts to 704.7, 624.7 & 500.7 thousand Dinars from stands of site index 28, 25 and 22, respectively. At high level of management it amounts to 844.5, 748.7 & 600.0 thousand Dinars for respective stands.
Fig 1a. Millable wood percent at low, medium and high level of management (Site Index 28)

Fig 1b. Millable wood percent at low, medium and high level of management (Site Index 25)

Fig 1c. Millable wood percent at low, medium and high level of management (Site Index 22)
Fig 1d. Millable percent of sleeper-logs only (at low, medium and high level management (Site Index

Fig 1e. Millable percent of sleeper-log only (at low, medium and high level management, (Site Index 25)

Fig 1f. Millable percent of sleeper-log only at low, medium and high level of management (Site Index 22)
Strict application of FMS with 8th last thinning at age 27, a rotation of 35 years and a minimum of five years between last thinning and final cut and at low level (0.3) of management lead to the results indicated hereafter. The highest NPV per feddan is achieved at rotation age 33. The higher NPV are 57.9, 37.6 & 13.4 thousand Dinars for stands of site index 28, 25, and 22, respectively. The financial rotation age under FMS is, therefore, 33 years. Figure (2b) displays the Net present value per feddan for a perpetual series of rotation length of 33 through 35 years for Foggie prescribed management strategy (base model). At high management level (0.75) the higher NPVs are 74.7, 51.2, and 23.7, respectively (figure 2d). End of rotation net income per feddan at low level of management amounts to 665.1, 576.4 & 447.6 thousand Dinars from stands of site index 28, 25 and 22, respectively. At high level of management it amounts to 780.6, 676.5 & 525.3 thousand Dinars for respective stands.

These results imply that management of stands of site index 22 according to Jackson strategy yields logs large enough to produce a single sleeper at rotation age of 26 years. Similar result applies to stands of site index 25 with a difference that the minimum required log dimensions are obtained earlier (commencing at age 18) than that of stands of site index 22 (commencing at age 25). Management of stands of site index 28 according to Jackson strategy yields logs large enough to produce double sleepers at rotation age of 26 years.

The application of Foggie management strategy produces different results. Stands of site index 22 yields logs large enough to produce a single sleeper at rotation age of 33 years. Stands of site index 25 yields logs large enough to produce double sleepers at rotation age of 33 years. Stands of site index 28 yields logs large enough to produce triple sleepers at rotation age of 33 years.
Title: Economic evaluation of two management strategies of Acacia nilotica plantations grown for saw log production along the Blue Nile, south of Sennar Dam, Sudan. Dafa-Alla, D. M., Ph.D. thesis.

Fig. 2a Net present value per feddan for sawlog production under Jackson management strategy (Low level management, perpetual rotations)

<table>
<thead>
<tr>
<th>Rotation age (year)</th>
<th>Site Index 22</th>
<th>Site Index 25</th>
<th>Site Index 28</th>
</tr>
</thead>
<tbody>
<tr>
<td>26</td>
<td>11.8</td>
<td>36.4</td>
<td>59.8</td>
</tr>
<tr>
<td>27</td>
<td>8.6</td>
<td>32.2</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>5.8</td>
<td>28.4</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>3.3</td>
<td>25.1</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>1.0</td>
<td>22.2</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 2b Net present value per feddan for sawlog production under Foggie management strategy (Low level management, perpetual rotations)

<table>
<thead>
<tr>
<th>Rotation age (year)</th>
<th>Site Index 22</th>
<th>Site Index 25</th>
<th>Site Index 28</th>
</tr>
</thead>
<tbody>
<tr>
<td>33</td>
<td>13.4</td>
<td>37.6</td>
<td>53.6</td>
</tr>
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Fig. 2c. Net present value per feddan for sawlog production under Jackson management strategy (high level management, perpetual rotations)

<table>
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<tr>
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Fig 2d. Net present value per feddan for sawlog production under Foggie management strategy (high level management, perpetual rotations)

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<th>NPV 'SD. 000'/feddan</th>
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<tr>
<td></td>
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<td>69.5</td>
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</table>
Fig 2e. Net present value per feddan for railway sleeper production at financial rotation age (Low level management, perpetual rotations)

Fig 2f. Net present value per feddan for railway sleeper production at financial rotation age (perpetual rotations, high level management)
Estimation of net present value per feddan with capitalized net income from sleeper production inclusive yields the following results. Strict application of JMS produces net present value of 75.4, 46.7, and 14.4 thousand Dinars at low level (0.3) of management. FMS application produces net present value of 71.2, 45.5, and 18.8 thousand Dinars at low level (0.3) of management (figure 2e). At high level management JMS application yields 95.1, 59.0, and 25.1 thousand Dinars, while FMS produces 88.3, 59.2, and 29.2 thousand Dinars (figure 2f).

4.4 Productivity status of existing Sunt stands:

Table (10) displays estimated production variables of final felling compartments felled in 2002. The mean number of stems per ha out of four compartments of site index 16 at age 25-28 is 82 stems. The mean number of stems per ha out of two compartments of site indexes of age 25 is 143 stems. The mean basal area per ha for the two compartments of site index 25 is 18m². The age of final felling compartments has declined to a range of 25 – 27 years. Appendix (18) shows productivity characteristics of the final felling compartments for the year 2002 as reported by the Inventory Directorate of the FNC, Central Sector. The mean millable percent of 8 final felling compartments is 47%, with a range of 26% – 61%.

With respect to log production results show that an average 7 to 8 logs (4 - 5 state logs and 2-3 commercial logs) are produced per tree from Hedaibat forest reserve (Site index 25). While an average of 5 to 6 logs (3 - 4 state logs and 1-2 commercial logs) are produced per tree from Gezair forest reserve (Site index 16). The millable volume amounts for 67% and 53% of standing volume at Hedaibat (SI 25) and Gezair (SI 16), respectively (Appendix 10).
4.5 Financial cost benefit analyses of alternative management strategies:

a. The case of perpetual series of like rotations:

Figures (3a -3c) display NPV s (‘000 S.D.) per feddan of base and alternative management strategies for Sunt stands of site index 22, 25 and 28 managed according to FMS and JMS at low level of management. Figures (4a-4c) display NPV s (‘000 S.D.) per feddan of base and alternative management strategies for Sunt stands of site index 22, 25 and 28 managed according to FMS and JMS at high level of management.

The base mode with bole height: total height ratio of 0.3 (FMS₀, JMS₀): Appendixes (19a, c & e) show NPV s (‘000 S.D.) per feddan (57.9, 37.6 & 13.4) for stands of site indexes 28, 25 and 22 managed according to FMS (base model) for 0.3 bole: total height ratios, respectively. Appendixes (19b, d & f) show NPV s (‘000 S.D.) per feddan (59.8, 36.4 & 11.8) for stands of site indexes 28, 25 and 22 managed according to JMS (base model) for 0.3 bole: total height ratios, respectively.

The base model with improvement of bole height: total height ratio to 0.75 (FMS₁, JMS₁): Improvement of bole height: total height ratio from 0.3 to 0.75 resulted in higher NPV s per feddan for Sunt stands managed according to JMS and FMS. Appendix (20a) shows NPVs (‘000 S.D.) per feddan (74.7) for stands of site indexes 28 managed according to FMS (base model) for 0.75 bole: total height ratio. Appendix (20b) shows NPV s (‘000 S.D.) per feddan (73.2) for stands of site indexes 28 managed according to JMS (base model) for 0.75 bole: total height ratio.

Establishment of crops through taungya with bole height: total height ratio of 0.3 (FMS₂, JMS₂): The practice of taungya improves the returns to land as a fixed factor relative to the base model.
Appendix 21a displays NPV (’000 S.D.) per feddan (78.4) for stands managed according to FMS, established through taungya with bole height: total height ratio of 0.3, for stands of site indexes 28. Appendix 21b displays NPV (’000 S.D.) per feddan (79.1) for stands managed according to JMS, established through taungya with bole height: total height ratio of 0.3 for site index 28.

Establishment of crops through taungya with bole height: total height ratio of 0.75(FMS, JMS): The practice of taungya together with increased bole height: total height ratio improved the returns to land relative to the base model. Appendix 22a displays NPV (’000 S.D.) per feddan (93.5) for stands managed according to FMS, established through taungya with bole height: total height ratio of 0.75 for site index 28. Appendix 22b displays NPV (’000 S.D.) per feddan (92.7) for stands managed according to JMS, established through taungya with bole height: total height ratio of 0.75 for site index 28.

Advanced thinning with bole height: total height ratio of 0.3(FMS, JMS): Advancement of thinning generated better income per feddan compared to base model. Appendix 23a, displays NPV ('000 S.D.) per feddan (69.8) for stands managed according to FMS, thinning advanced one year with bole height: total height ratio of 0.3, for site index 28. Appendix 23b, displays NPV ('000 S.D.) per feddan (67.9) for stands managed according to JMS, thinning advanced one year with bole height: total height ratio of 0.3, for site index 28.

Advanced thinning with bole height: total height ratio of 0.75(FMS, JMS): Advancement of thinning with bole height: total height ratio of 0.75 generated higher NPV per feddan compared to base model. Appendix 24a, displays NPV ('000 S.D.) per feddan (85.8) for stands managed according to FMS, thinning advanced one year with bole height: total height ratio of 0.75, for
site index 28. Appendix 24b displays NPV (’000 S.D.) per feddan (73.4) for stands managed according to JMS, thinning advanced one year with bole height: total height ratio of 0.75, for site index 28.

Combined taungya and advanced thinning with bole height: total height ratio of 0.3 (FMS₆, JMS₆): The combination of taungya and advanced thinning in stands of site index 28 with bole height: total height ratio of 0.3 further improved NPV per feddan. Appendix 25a, displays NPV (’000 S.D.) per feddan (88.6) for stands managed according to FMS, combined taungya and thinning advanced one year with bole height: total height ratio of 0.3, for site indexes 28. Appendix 25b, displays NPV (’000 S.D.) per feddan (87.4) for stands managed according to JMS, combined taungya and thinning advanced one year with bole height: total height ratio of 0.3, for site indexes 28.

Combined taungya and advanced thinning with bole height: total height ratio of 0.75 (FMS₇, JMS₇): The combination of taungya and advanced thinning in stands of site index 28 with bole height: total height ratio of 0.75 generated the highest NPV per feddan relative to base model. Appendix 26a, displays NPV (’000 S.D.) per feddan (104.6) for stands managed according to FMS, combined taungya and thinning advanced one year with bole height: total height ratio of 0.75, for site indexes 28. Appendix 26b, displays NPV (’000 S.D.) per feddan (92.9) for stands managed according to JMS, combined taungya and thinning advanced one year with bole height: total height ratio of 0.75, for site indexes 28.

Delay of regeneration by one season with bole height: total height ratio of 0.3 (FMS₈, JMS₈): Delay of regeneration of land due planting by one season reduced NPV (’000 S.D.) per feddan to 47.8, 26.9, and 3.5 for stands of site index 28, 25 and 22 and managed according to FMS, and
reduced NPV (‘000 S.D.) per feddan to 48.5, 27.6 and 3.91 for stands of site index 28, 25 and 22 and managed according to JMS, respectively (figure 7).

Change in prescribed yield to actually harvested yield per unit area (FMS10, JMS10): Application of mean yield (127.84 m$^3$ ha$^{-1}$) of final felling compartments in stands of site index 25 actually harvested in 2002, reduced NPV (‘000 S.D.) per feddan to 15.2 compared to 33.3 achieved for stands of similar site index and managed according to JMS, and reduced NPV (‘000 S.D.) per feddan to 25.2 compared to 34.7 achieved for stands of similar site index and managed according to FMS (figure 8).

b. The case of single rotation: Figures (5a -5c) display NPV (‘000 S.D.) per feddan of base and alternative management strategies for Sunt stands managed according to FMS and JMS at low level management. Figures (6a -6c) display NPV s (‘000 S.D.) per feddan of base and alternative management strategies for Sunt stands managed according to FMS and JMS at high level of management. For both single rotation and perpetual series of like rotations, results show that establishment of Sunt plantations with the aid of taungya practice, advanced thinning for stands of higher quality classes and the combination of both improve the NPV s per feddan relative to the base model. However, the influence on the NPV is of different magnitude. Obviously, improvement of millable percentage from 0.3 to 0.75 results in higher NPV s per feddan for Sunt stands managed according to either strategy. Delay of regeneration and yield reduction per unit area reduced Net present value per feddan.
Fig 3a. Effects of taungya, advanced thinning and their combination on net present value at low level management (perpetual rotations, Site index 28)

Fig 3b. Effects of taungya practice on net present value at low level management (perpetual rotations, Site Index 25)

Fig 3c. Effects of taungya practice on net present value at low level management (perpetual rotations, Site Index 22)
Fig 4a. Effects of taungya, advanced thinning and their combination on net present value at high level management (perpetual rotations, Site Index 28)

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<td>JMS1/28</td>
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<tr>
<td>JMS5/28</td>
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Fig 4b. Effect of taungya practice on net present value at high level management (perpetual rotations, Site Index 25)

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<tr>
<td>FMS3/25</td>
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<td>JMS1/25</td>
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<td>JMS3/25</td>
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Fig 4c. Effects of taungya practice on net present value at high level management (perpetual rotations, Site Index 22)

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<td>11.0</td>
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<td>JMS3/22</td>
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Fig 5a. Effects of taungya, advanced thinning and their combination on net present value at low level management (single rotation, Site Index 28)

Fig 5b. Effects of taungya on net present value at low level management (single rotation, Site Index 25)

Fig 5c. Effects of taungya on net present value at low level management (single rotation, Site Index 22)
Fig 6a. Effects of taungya, advanced thinning and their combination on net present value at high level management (single rotation, Site Index 28)

Fig 6b. Effects of taungya on net present value at high level management (Single rotation, Site Index 25)
Fig. 6c. Effects of taungys on net present value at high level management (single rotation, Site Index 22)

Fig. 7. Effect of delay of regeneration on net present value at low level of management (Single rotation, site index 22, 25 & 28)
Fig 8. Effect of reduction in yield of final cut on net present value at low level management (Single rotation, Site index 25)

Legend: JMS₀ = Base model; JMS₁₀ = Reduction of yield of final cut
Table 10. Stocking characteristics of final felling compartments, 2002.

<table>
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<tr>
<th>Forest</th>
<th>Cmpt</th>
<th>Area</th>
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<th>Dom</th>
<th>Site</th>
<th>No. of</th>
<th>DBH</th>
<th>BA/ha</th>
<th>Mean</th>
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<td>ht (m)</td>
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<td>(m)</td>
<td>(m2)</td>
<td>ht (m)</td>
<td>ha (m3)</td>
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<tr>
<td></td>
<td>ha</td>
<td>ha</td>
<td>ha^2</td>
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<td>d</td>
<td>e</td>
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<td>25</td>
<td>164</td>
<td>0.40</td>
<td>20.1</td>
<td>30.0</td>
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</table>

Source: This survey.

Legend:
1. Comp. = Compartment. 2. Dom. ht = dominant height. 3. BA (m²/ha) = (D²)/4*3.142*Number of stems/ha.
4. Volume (m³/ha) = BA/ha* ht * form factor.
Chapter five: Discussion

5.1 Work and time studies for cost estimation;

5.1.1 Costing of forest operations:

Estimated operational costs are expressed on per unit basis. Establishment and tending labour is expressed as man-days or machine-day per feddan of land. For wood products, costs are expressed per unit of stacked or solid $m^3$ of firewood or $ft^3$ of round wood as applicable. The expression of operational costs as man-days and machine-days per unit provides the bases for future comparisons without necessarily resorting to financial estimates, particularly with changes in prices of inputs and outputs. While Sunt crop is establishment through broadcasting of treated and untreated seeds, and sowing in pits, only the later is assessed in this study for entirely practical reasons. However, for the complete estimation of operational cost per unit area labour and material quantities required for seed treatment and broadcasting are added.

The practice of singling operation involves the use of labour mainly since the material requirements are consumable ones. It is quite different in terms of ease and cost if operation is made in the first year or before the rains of second year than later on. While it is possible to combine singling with weeding, delayed singling involves higher costs and levels of risk as trees develop. The use of taungya helps in early practice of singling. In fact, if properly exercised, the practice of singling in first or second year reduce spacing of trees to $2m \times 2m$ and, therefore, may provide an alternative management strategy compared to ignored or delayed singling, or first thinning at age six.

The performance of pre-commercial thinning at age six is onerous particularly if prior singling is omitted. The operation, however, is relatively made easy with the use of power driven
pruning machines and skilled forest workers. Examination of pre-commercial thinning practice indicates that the number of trees retained at age six is much higher than the prescribed ones (appendix 27) which implies that the same compartments need to be revisited sooner than prescribed. That the level and presence of officers actually in charge of the operation is low. There is a critical need to establish site index map for different stands so as to apply the prescribed thinning rules.

The abandoning of permanent sample plots discontinues the flow of regular biological and economical data. There are no recent estimates of costs of different establishment, tending and harvesting operations to compare with. Material cost is dominant in the seed sowing operation where it constitutes 48% of total cost per feddan. This finding calls for a rational use of seeds at establishment times. The current practice of placing more than 10 seeds per pit is wasteful and uneconomic (Sharawi and Dafa-Alla, 1999).

Sampling field operations in an on-farm research is problematic compared to the within-station one. The sample size of seed sowing operation is relatively small for two reasons. The operation was investigated in only one season. Environmental factors acted as limiting elements where re-forestation programs were not performed during the second year of the research period, as there was no flooding. The adoption of the FNC of different sowing method – pit sowing prior to rains- in the third season was a different method than that investigated earlier. The unavailability of the particulars of earlier thinnings in terms of timing, intensity, inputs involved, output produced, and income generated made it useless to this study to gather data on the second and third thinning prescribed in the current working plan.
5.1.2 Costing of sawmilling and sawmilling-related operations:

The felling power saw belongs to a private company. It is responsible for the felling operations in the final felling compartments according to the results of the sealed bid process. The operator is contracted on per log basis. Cutting of logs cost SD.125, each. Cost of fuel and engine oil is divided (50%) between the operator and the company. The company rents the machine for the operator for 25% of log felling rate. Although privatized, the final felling operation requires further controls in order to improve productivity per unit time and reduce unit cost.

Skidding operations are partially privatised. Private farm tractors are used for skidding of logs with the FNC provides the fuel. It is observed that there is no predetermined minimum quota of logs to be skidded per working day. It observed that, too, the helpers are FNC workers who receive daily wages together with incentives per log skidded. This double counting adds to the cost of skidding per unit of output. The setting of a predetermined quota helps the accumulation of logs and smooth out the log transport process.

Originally skidding of logs in the practice of forestry in Blue Nile is done with the aid of two labors, in addition to the tractor operator. One labour is for each of hooking and unhooking of logs. In some cases, the tractor operator acted as unhooking worker. This was the case in Hedaibat forest where as a result the thick remaining small thorny branches and twigs, the hooking workers required much more time to clear the way and prepare logs for hooking. This time was long enough to allow the driver to unhook the logs.
The loading and unloading processes are privatised where manual labours are contracted on a per log basis. Manual loading and unloading is time consuming and involves a high level of risk. Transport of logs is made using the ordinary Lorries which carries small loads. Both affect the sawmilling cost and the log transport season may well extend to influence the preparations of the next establishment season. Mechanical loading of logs reduces the associated levels of risk, saves considerable time and efforts, and thereby reduce operational cost and let log transport operations finishes earlier, thus provide enough time for site preparation for replanting the cut area in the same year as prescribed in the management plans. However, efficient mechanical loading using loaders requires a set of stand by trucks ready to move continuously from stump site to sawmill yards. Neither loaders nor ready trucks are available for the job in present practice.

The relatively high conversion factor of Es Suki sawmill of 59.83 is obtained because utmost attention was given to produce the smallest possible sawn piece from the log. This level of accuracy is not maintained during normal working days in which the mean conversion factor is about 40%. This result agrees with that (55%) obtained by Nile (1996) and with that (57.63%) obtained by Suliaman (1987) with improved bucking and controlled sawing.

Sawmilling costs is estimated as per sawn ft\(^3\). The cost of producing SRS is specifically addressed. Total cost of producing (felling, skidding, transport and sawing) railway sleeper at Es Suki sawmill for 2002 is S.D. 2266.4. This is slightly less than the estimate (S.D. 2491.9) made by the FNC for 2002. This cost could be reduced by 13% (S.D. 1969), 26% (S.D. 1678), and 33% (S.D. 1514), if the conversion factor is improved by 6%, 14% and 20%, respectively.
5.2 The technical rotation for sawlog production

The determination of the technical rotation (table 9) has several policy and practice implications. One, management objectives and strategies could be based on site potentiality and limit the process of saw log production to sites of high quality, with others utilized for firewood production on a shorter rotation. Stands of site index 16 and 19 should be removed from the sawn wood working circle and be managed for the production of other than sawlogs products. Stands of site index 28 and 25 are the best to produce saw logs. Stands of site index 22 are intermediate and the economics and logistics of its utilization for sleeper-producing saw logs has to be eventually addressed. These findings are in agreement with those presented by Khan (1964) and supported by Foggie (1968) who states that "Sunt stands which are capable of producing SRS logs on a fairly short rotation which were all between Q.C. 1 and Q.C. 11/111, mediocre crops which were capable of producing SRS logs eventually on a longer rotation these were largely Q. C. 111/1V , and poor crops which were most unlikely ever to yield sleeper size logs, comprising the rest of the 111/1V and IV quality classes".

The process of re-organization of compartments seems indispensable. This is supported by the same recommendation made by Hetherington and El-Siddig (1983/84) who indicate that the compartmentation system may be one of the major factors resulting in the alarming deviation of the structure and failure to attain sustainable production. The Inventory Directorate of the FNC (1998) also supports it.

A notable result from the examination of the yield tables and the conversion factor of the state sawmills at present is that Sunt stands of site index 28 produce logs large enough to produce a maximum of 3 sleepers. This indicate a relative decline in stocking characteristics as Jackson (1959) indicates that it would be possible to produce 4 sleepers from logs with minimum mid
log diameter of 65 cm. However Eltayeb (1985) yield tables indicates that the DBH of the trees of the remaining crop at age 36 is 53.1 cm and 60.8 cm for site index 25 and site index 28, respectively. This potentiality is thus ruled out.

The minimum diameters required to produce railway sleepers are determined with due consideration to the sawmill conversion factor. Therefore, any improvement of the mill environment, in terms of machine efficiency and log characteristics that lead to the utilization of smaller diameters, affects the range of years of the technical rotation.

5.3 Determination of optimal rotation

5.3.1 Estimation of millable wood percent during the rotation:

Application of the management strategy prescribed by Jackson or Foggie for the management of riverine Acacia nilotica stands for saw log production involves the production of sizeable quantities of firewood from both intermediate and final cuts. The share of firewood and millable wood in the quantity harvested from thinning or final cut is important for the analysis of volume and value flows along the rotation. The specific shares of millable and firewood for Acacia nilotica stands growing on different sites are not known. The proposed percentages of millable and non-millable wood, estimated at different thinning times and at rotation ages for stands of site index 28 and 25 are presented in this study (Fig 1a-1f).

The results are in agreement with Foggie (1968) who indicates that actual exploitable volume for saw timber is to be only 67% of the gross stem volume down to 9.5” girth for stands of quality class I – II/III” for a rotation of 35 years. In this study the proposed mean of total millable percentages of the three sites at age 30 are 67.1, 43.7, and 25.5 at bole height ratio of
0.8, 0.5, and 0.3, respectively. The proposed percentages are in line with the results of this study actual estimation of millable volume (57%) of total stem volume of final felling compartments (age 25) at Hedaibat stump site (SI 25). In the proposed percentage, it is estimated as equal to 58.2% and 52.1% for bole height ratio of 0.8 and 0.7, respectively. The proposed percentages are also consistent with the percentages indicated in FNC final felling (age 25-27 years) reports (2002/3). The limits of the bole: total tree height is consistent with those indicated by Goda (1985), i.e. timber height is taken as 44.6% and 37.4% of total height for site types Gs-Ks and M, respectively in young crops. In old crops the ratios are 82.4% and 82% for site type Gs-Ks and M (Goda, 1985), respectively.

The method of measuring wood content affects the small end dimensions required and the percentage of millable wood. The Die square method to determine true content measure, for example, is adopted where it is desired to ascertain the volume of the largest size of a square blauk which can be cut from a round log (James, 1966). The shape of the curve of the proposed percentages depends on the diameter at breast height as related to age and site index. The closer the required diameter to the log small-end diameter the higher the percentage. This explains the ups and downs of the curve.

5.3.2 The financial rotation age of Sunt stands under FMS and JMS (base model):

Net present value per feddan for sawlog production:

Within the range of the technical rotation age of sawlog production, financial rotation age that maximizes net present value at 12% before tax discount rate is determined as 33 years for FMS with a NPVs per feddan of 57.9, 37.6, 13.4 thousand Dinars for stands of site index 28, 25, and 22, respectively. This means that the maximum the FNC could pay for a feddan of bare land
and still earn the minimum acceptable rate of return of 12% is 57.9, 37.6, 13.4 thousand Dinars for stands of site index 28, 25, and 22, respectively if the indicated cash flows of the FMS occur.

For stands managed according to JMS the financial rotation age is determined as 26 years. The higher NPV's per feddan are 59.8, 36.4, 11.8 thousand Dinars for stands of site index 28, 25, and 22, respectively. Again this simply means that the maximum the FNC could pay for a feddan of bare land and still earn the minimum acceptable rate of return of 12% is 59.8, 36.4, 11.8 thousand Dinars for stands of site index 28, 25, and 22, respectively if the stated cash flows of the JMS is materialized. It is obvious that site quality influences the net present value per unit area. Within each management strategy, willingness to pay for land (WPL) values decline with decreasing site quality which imply relatively lower output per unit area or low quality products with lower prices.

The positive net present value of stands of site index 28, 25 and 22 at different rotation lengths implies that the crop is financially acceptable and the actual felling time may be dictated by factors other than profitability. This is particularly true as net present values of rotations a few years shorter or longer than optimal are not much less than that of the optimum. This gives some flexibility of rotation length, for example if there are constraints on the rate at which a large even-aged forest can be harvested (Price, 1989). If the WPL values are low enough, timber is no longer the chosen use.

The current policy of establishing prices of wood products from final felling of *A. nilotica* is theoretically acceptable since it is based on competition and a bidding process. Pricing of
firewood of intermediate thinnings is made with due consideration to wood quality. Prices of firewood increase by a fixed annual increment up to a limit after which they remain constant up to harvest age. Volumes of wood produced of thinning constitute a sizable proportion of total volume. Compared to a constant stumpage price per unit volume, increasing stumpage prices over time lengthen the optimal rotation (Klemperer, 1996).

The impact of applying fixed wood price affects the choice of the management strategy and the financial rotation that is determined accordingly. While Jackson management strategy produces logs that are capable of producing a maximum of two sleepers in fertile stands of site index 28 at financial rotation age, Foggie management strategy produces logs that are capable of producing up to three sleepers. These results mean that additional wood accumulation beyond the determined financial rotation age of 26 is not financially justified given the policy of fixed wood prices.

Two important wood price-related factors worth special attention to explain why the financial rotation age lies at the lower end of the range of rotation lengths assessed in this study i.e. age 26 for a range of 26-30 years, and age 33 for a range of 33-35 years for JMS and FMS, respectively. First, constant price per unit of output of round wood at different rotation ages and for firewood after age 15 in the present pricing policy. With discounting applied, present values of later incomes are smaller than the present value of the same incomes due early in the rotation. This promotes shorter rotations. Second, relative importance of sawlogs to firewood is not reflected in their unit prices. Management objective of producing sawlogs large enough to produce railway sleeper is not satisfactorily reflected in the present pricing policy. Present price per unit ratio (firewood: saw log) of 0.6 gives higher weight to firewood relative to round saw log particularly if this is connected to early ages at which firewood is produced. The selection
of lower end of the range of rotation lengths assessed is an indication of the relative analogy of systems analyzed to that of short rotation crops for firewood production. Increasing price per unit with improved wood quality lengthen the rotations. One route reasonable to be followed is to make use of the technical rotation determined in this study, quality differences between imported sleepers and locally produced Sunt sleepers, cif Port-Sudan (or Atbara-delivered) price of imported sleepers to estimate an equivalent price per unit of round wood.

Net present value per feddan with production of railway sleepers inclusive:

Extension of financial analyses to include net income from sawmilling operations for SRS production yields the following results. First, JMS is financially more attractive than FMS in more productive stands of site index 28 at low (75.4 vs 71.2) as well as high (95.1 vs 88.3) level of management. Second, FMS is financially superior in less productive stands of site index 22 at low (18.8 vs 14.4) as well as high (29.2 vs 25.1) level of management. FMS is financially superior in stands of site index 25 at both low and high levels of management. The difference, however, in net present value per feddan for stands of site index 25 is very small (0.9% and 0.3% at low and high level of management, respectively) to the extent that JMS and FMS can be considered –for practical and organizational purposes- equally attractive. It is evident that there is a need to assess the profitability of stands of site index 22 managed according to FMS for saw log production relative to other production objectives e.g. firewood production in a shorter rotation.

5.4 Management of existing Sunt stands:

Exploring the relative stocking of current A. nilotica stands reveals that the mean number of stems per ha out of four compartments of site index 16 at age 25-28 is 82 stems compared to
326 in the prescribed yield tables produced by Eltayeb (1985) for respective ages and site indexes. This is in agreement with the figures produced by Ahmed (in: Elsiddig, 2002) who indicates that stocking falls to the range of 25-44 trees per feddan (60-104 trees per ha) and the dbh ranges between 37 and 48 cm. Relative stocking of existing stands in terms of number of stems per ha is low. The mean basal area per ha for the four compartments is 8.9 m² compared to 16.4/ha (stocked) in the yield tables produced by Eltayeb (1985). This is smaller basal area per unit area compared to that indicated in the yield tables. The mean dbh of the trees of the final felling compartments was 40 cm and 41 cm compared to 23.9 cm and 30.1 cm at the same age in stands of site index 16 and 19, respectively. Elsiddig (2002) indicates that the diameter at breast height of the mean tree has declined. While it is at present in the range of 30-45 cm, it was in the range of 45-62 cm.

The actual stocking characteristics of stands of site index 25 show reasonable agreement with indexed stocking. The mean number of stems per ha out of two compartments of age 25 are 143 stems compared to 122 stems. The mean basal area per ha was 18m² equal to that of the remaining crop of similar site index and crop age as prescribed in the yield tables produced by Eltayeb (1985).

It is evident that the actually harvested volumes per hectare are far less than the indexed ones. With a mean of 44.4%, the harvested to indexed volume ratios are 43%, 26%, 65%, 50% for stands of site index 16, and, 28%, 58% for stands of site index 19, and, 44% and 42% for stands of site index 25 when per stocked-hectare is considered for the mentioned compartments (appendix 18). This may be attributed directly to the low number of stems retained per unit area up to this age and the different management practices applied. Smaller figures result if total area – rather than stocked area- is considered. With a mean of 47%, percentage of millable
to non-millable volumes of the same final felling compartments are 19%, 16.5%, 25%, 21%,
22%, 55%, 36% and 30% (appendix 18).

The discrepancies between the characteristics of the existing stands and that indicated in the
yield tables indicate that past management during the rotation of existing stands was not in line
with the prescribed management strategy of *Acacia nilotica* crops grown for saw log
production. The crop were either improperly spaced at establishment or more likely heavily
thinned prior to final felling. Elsiddig (2002) supports this finding stating that at present the
final felling crop is usually less than fifty trees per feddan, ranging between 25 and 35 trees. He
continued that this might be because of heavy thinnings, or that successive thinnings continued
beyond the age of twenty years.

The age of final felling has declined to a range of 25 – 27 years. This is far less than the
rotation of maximum wood production recommended by Eltayeb (1985), Jackson (1959),
Foggie (1968), and Goda (1987) for site type Maya. Current felling age matches that
recommended by Goda (1987) for site type Gs-Ks. The crop, however, was not managed as
prescribed by Goda (1987). The reduction of felling age implies a deviation from the
prescribed management strategies. With the expiry of 1969/1978 working plan, Sunt forests of
the Blue Nile were operated under provisional annual felling schedules. This approach of
annual felling has resulted in a wide variation of thinning intervals and intensities and a wide
variation in the area to be felled and planted annually (FNC, 1998).

Results of saw log production of final felling compartments show that an average 7 to 8 logs (4
- 5 state logs and 2-3 commercial logs) are produced per tree from Hedaibat forest reserve (Site
index 25). While an average of 5 to 6 logs (3 - 4 state logs and 1-2 commercial logs) are
produced per tree from Gezair forest reserve (Site index 16). The Inventory Directorate of the FNC reports that final harvest (2002) volumes were made of 36.4%, 9.3%, and 47.9% of state logs, private logs, and firewood, respectively. This still remain low compared to an exploitable wood volume of 67% of gross stem volume stated by Foggie (1969) and Goda (1982). The decline of sleeper production per feddan and per tree may be due to the decline of the stem number per feddan and the reduction of average stem size of the mean tree due to abandoning of final felling selection and marking used to be carried out at the third thinning (Elsiddig, 2002). The reduced percentage of millable wood may be attributed to the heavy thinning. Elsiddig (2002) indicates that heavy thinning, usually practiced at present, induced heavy branching resulting in short boles that may have large size but shorter than the standard length for the railway sleeper production. That is contrary to the situation in the past when long straight boles were obtained having sometimes twice the standard length for sleeper production.

The low productivity per unit area has a significant impact on the economics and sustainability of the A. nilotica cropping system and on the important subsequent sawmilling industry. Low productivity per unit area means that larger areas have to be cut to meet a specified demand for saw logs and railway sleepers. This very fact may be responsible for the drop of current felling age. The impact on sawmilling industry is many folds. First, the cost per unit of millable round wood is higher. Second, the supply of good quality saw logs is in short resulting in non-functioning of the sawmills for several months a year leaving idle the mill, set of skilled labour and a paid work force. Third, sawmilling cost is higher for logs with small diameters and with irregularities of shape.
Stocking density and diameters of final-crop trees influences felling cost per unit area and per unit of output. Higher densities reduce per unit cost as the overheads are distributed over a large number of units than with low densities. Difficulties arise in the management of extra large diameters in the skidding, loading and unloading and sawmilling which may require extra labour or machine effort. The volumes of leftover logs are deducted from the millable volume and moved to the firewood representing unnecessary extra cost.

5.5 Financial cost benefit analyses of alternative management strategies:

a. Perpetual series of like rotations:

Establishment of A. nilotica stands through taungya (FMS2 and JMS2): The contribution of agroforestry to the economy of A. nilotica cropping system is in the sort of cost reduction made through the provision of labour, mainly. Labour provision by beneficial farmers covers some of establishment and tending operations. Sowing of A. nilotica seeds is a technical operation reserved to be performed by skilled forest workers. Supervisory cost is reserved, too, as the practice of taungya within forest reserves requires the same, if not more, supervision and controls. The reduced costs are that of land clearance, protection, first weedings and second weeding at a per feddan cost of S.D. 2000, 2124.3, 6500 and 4000, respectively in the first year. Protection and third weeding in the second year at a per feddan cost of S.D 2124.3 and 2000, respectively. The estimated mandays saved per feddan are 15, 8, 8, 5, and 8 for land clearance, protection, first weeding, second weeding, and singling operations in the first year, respectively, and 8 and 5 mandays for protection and third weeding, respectively, in the second year. These figures are in consistent with those reported by Suliaman (2003). The practice of taungya reduced establishment cost per feddan from S.D. 26557.6 and S.D.7202.6 to S.D. 11933.3 and S.D. 3078.3 in the first and second years of establishment, respectively. In terms of percentage, cost reduction amounts to more than 50% in the first and second years. Reduced
costs have the same weight as increased income of the same amount and timing of occurrence and its economic significance stems out because it takes place early in stand development.

The with- and without-project analyses indicate that the NPV per feddan of the with-taungya situation is improved for FMS by 35.4% and 52.7% in stands of site index 28 and 25, respectively. For JMS the improvements are 35.7% and 54.8% in stands of site index 28 and 25, respectively. These improvements express the relative importance of cost reduction in less productive sites than on more productive sites. The percent improvement is higher for poorer sites because the income originally generated in the cash flow is smaller than in sites that are more productive. While economically appealing, the technical suitability of any particular stands for taungya adoption has to be assessed. This has been confirmed recently, for example, in El-Gezair forest reserve as pointed out by Suliaman (2003) who indicates that the most important research finding was that the intercropping period has been increased to two seasons, provided the proper tending of sunt seedlings i.e. pruning and singling. He further added that a reduction and saving of the initial cost of sunt establishment for 48 man-days/feddan/year.

A practical significance of the use of taungya for establishment of *Acacia nilotica* is that it relieves the FNC from sizeable spending that takes place in a limited time period. It also provides the opportunity to fully utilize the site potential through the growing of arable crops without necessarily having a negative impact on *A. nilotica* crop. However, because of land hunger utmost care and strict controls have to be applied to eliminate any leakages in application and guarantee correct stand development.
Advancement the timing of thinning in stands of site index 28 (FMS4 and JMS4): Advancing the timing of thinning in stands of site index 28 is promoted in this study. A higher site quality requires earlier thinning for a given initial density because competition begins earlier (Danial et al., 1979). But at 5 years in quality class I crops and 6 years in QC I/II-III crops it is advisable to carry out a preliminary brashing … and in very dense crops an actual thinning may be carried out and the crop reduced to 500-600 stems per feddan (Foggie, 1968). Booth (in De Veer, 1961) states that optimum age for first thinning of stands on good soils should be 5 or 6 years.

The principle of thinning out is to encourage the development of certain trees considered valuable, usually for economic purposes, by eliminating neighboring ones. This technique can only be used in closed stands. One must also be sure that the investment in terms of time and manpower guarantees reasonable economic returns in terms of the quality and quantity of the volumes harvested. Lessons learned from plantation thinning operations lead to think that under advanced thinning, the trees retained react weakly, while early thinning produces the best responses (Bellefontaine et al., 2000). The NPV of the without-advanced-thinning situation is less by 20.6% and 17.3% of the with-advanced-thinning for FMS and JMS, respectively.

Advancement the timing of thinning in stands of site index 28 established through taungya (FMS6 and JMS6): When advanced thinning is combined with taungya the with-project net present value improved by 53% and 51% than without-project situation for FMS and JMS, respectively. Both treatments apply positive effect on project returns. While taungya performs a cost-saving role, early thinning provides early income and helps in realizing targeted diameters.
Delay of regeneration by one season: failure to replant cut areas in the same year as the sustained yield model dictates may be attributed to natural (e.g. no or insufficient rains or seeds) or economical (no or insufficient forest development budget or irregular cash flow pattern) or other factors. Delay of regeneration treatment resulted in lowering Net present value for stands of all site indexes and under both FMS and JMS. This is not abnormal since delay of regeneration involves defer of income, suffer opportunity costs of unused land, labour and other resources, and lengthen the rotation.

Change in prescribed yield to actually harvested yield per unit area: improved yields over and above the prescribed yield per unit area increase NPVs and vise versa. The actually harvested yield per unit area for stands of site index 25 was much less than the prescribed one. The reduction in NPVs per feddan is understandable.

Improvement of bole height: total height ratio:

Proper forest management -involving timely practice of silvicultural and other operations-improves the quality and quantity of wood yield. This is particularly true if products of special size or quality are targeted. For stands of all site indexes and under any of FMS or JMS, improvement of millable percent adds to the Net present value per feddan.

b. The single rotation case:

Comparisons of NPVs per feddan for FMS and JMS reveal the same trend as discussed with the case of perpetual rotations. For all models analyzed, the NPV per feddan in the case of a single rotation is slightly less than that of a perpetual series of like rotations. When looked upon as the first rotation in an infinite series of like rotations, its per feddan NPV makes up the bulk of NPV of the infinite series. This could easily be explained by the fact that present values
of cash flows occurring after 30-35 years in the future, with an annual discounting rate as high as 12%, are very small if not negligible. Real income is generated from first rotation.
Chapter six: Conclusions and recommendations

The results of this research are limited to the sites investigated when assumptions made in this study hold.

6.1 Conclusions:

- Continuous generation of bio-physical and socio-economic information is seriously missing. Without these frequent readings, decisions on management and improvement of the system are difficult.

- The age limits for the technical rotation are a function of site quality, log characteristics and conversion factor and minimum log dimensions required to produce specific category. The better the site, however, the earlier the technical rotation.

- Within the limit of saw log production per se, FMS generates slightly higher net present value per feddan for stands established on all three sites and at low and high level of management. At this level, therefore, FMS is superior on JMS.

- With sawlog-sleeper-production seen as inseparable continuum, the addition of capitalized perpetual periodic net income from sleeper production affects ranking of alternative management strategies. JMS is financially more attractive than FMS in more productive stands of site index 28 at both low and high levels of management. FMS is financially superior in stands of site index 25 and 22 at both low and high levels of management. The difference, however, in net present value per feddan for stands of site index 25 is very small (2.7% and 0.2% at low and high level of management, respectively) and both strategies may be considered as financially equally attractive.

- The use of taungya practice in establishment of A. nilotica stands improves their profitability, provides investment opportunities for landless and better utilize the soil productivity potentials.
• Advancement of thinning in stands with better site qualities improves their overall profitability. When combined with taungya, they realize higher net present value per unit area relative to net present value of the system without them.

• The management of present A. nilotica stands doesn't follow either of the recommended strategies. Low relative normality, low productivity per unit area in quantity and quality, and reduction in harvest age are evidences of the deviation from rotation of sustainable production.

6.2 Recommendations:

6.2.1 Forest policy and practice:

➢ For A. nilotica, as well as other species, keeping of bio-physical and socio-economic data is indispensable. Resort to permanent sample plots, compartment books and log sheets are recommended in order to generate regular flow of information that is needed for forest management decisions.

➢ Though heavily studied, establishment of A. nilotica stands particularly the use of seeds as material inputs and methods of sowing is recommended to be re-visited. It is recommended that A. nilotica stands be established through the use of taungya practice with advancement of thinning by one year in stands of high site quality classes.

➢ Reorganization of compartments on site quality is recommended, management objectives and rotation ages are determined accordingly. The application of Jackson management strategy with the thinning procedures and selection of final crop trees should be adhered to with saw log production confined to stands of site indexes 28 and 25 mainly.
It is recommended that *A. nilotica* stands of site indexes 22 be managed for sleeper production, if necessary, according to FMS. *A. nilotica* system is recommended to be looked for as a continuum starting with crop establishment up to and including saw log production, sleeper production and marketing of sawn products.

- It is recommended that a log and lumber yield system be applied. This system provides a mill with a tool which can help them better understand and document the relationship between their log grades and the yield of lumber from those grades. This in turn allows the mill to better manage log and lumber inventories, revise log pricing based on solid yield data, and correlate yield and processing costs to improve profitability. In sorting of saw logs small end diameter is recommended to be used in replacement of the current practice of using mid log diameter.

### 6.2.2 Further research:

- A wider socio-economic research on the importance of *A. nilotica* plantations for the national economy is recommended. The opportunity cost of these forest lands -to produce saw logs- and other forestry inputs need to be assessed, from a national perspective, in relation to other potential land uses.

- Forest policy objectives of *A. nilotica* forests need to be investigated with a forecast for changes in energy balance towards non-wood alternatives in the future. Alternative forms of goods and services and potential markets are recommended to be addressed.

- A research on alternative management strategies for *A. nilotica* stands is recommended taking into account the reorganization of the forests into compartments on the bases of site quality classification.

- The pricing policy of raw wood, whether firewood or millable wood, and sawn wood is recommended to be investigated. The study should emphasize methods of offering
timber for sale, a reservation price for each product, and development of a mechanism for regular price updating.

- It is recommended that the percentages of millable and non millable wood proposed in this study be validated and / or improved through field testing in A. nilotica stands that are well managed and their characteristics fit in the yield tables of Eltayeb (1985).

- It is evident that there is a need to assess the profitability of stands of site index 22 managed according to FMS for saw log production relative to other production objectives e.g. firewood production in a shorter rotation.
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Economic evaluation of two management strategies of *Acacia nilotica (L.*)* plantations along the Blue Nile south of Sennar dam, Sudan

Ph.D. thesis

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